MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXVI. No. 1. NOVEMBER 1905.

PRICE TO NON-FELLOWS, 2s. 6d.

ANNOUNCEMENT OF PAPERS RECEIVED.

Post-cards, giving the titles of such Papers as have been received or promised up to the Tuesday preceding the day of the Ordinary Meeting, will be sent to such Fellows who inform the Assistant Secretary of their wish to receive them.

MEMOIRS.

Fellows are informed that in future a separate application for each volume of the *Memoirs* will not be required. Fellows sending their names to the Assistant Secretary will receive the volumes to which they are entitled, as they are issued, without further application.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY,

CONTAINING

PAPERS, ABSTRACTS OF PAPERS, AND

REPORTS OF THE PROCEEDINGS

OF THE SOCIETY

FROM NOVEMBER 1905 *TO NOVEMBER* 1906.

VOL. LXVI.

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MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXVI. NOVEMBER 10, 1905. No. 1

W. H. MAW, Esq., PRESIDENT, in the Chair.

Walter Sidney Adams, M.A., Solar Observatory, Mount Wilson, California, U.S.A.;
Ernest Percival Cotton, Lands and Survey Department, Lagos, West Africa;
Rev. Alexander C. Henderson, B.D., The Manse, Delting, Brae, Shetland, N.B.;
Rev. Frederick John Jervis-Smith, M.A., F.R.S., M.Inst.E.E., Trinity College, Oxford, and Battramsley House, Lymington, Hants; and
T. Hobart Pritchard, 5 Cotford Road, Thornton Heath, Surrey,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Lieut. George Alfred Alcock, R.N.R., c/o Shaw Savill & Albion Co., Royal Albert Dock (proposed by M. W. Campbell Hepworth);
Hugh Daniel Badcock, M.A., Assoc. Mem. Inst. C.E., Town Engineer, Pretoria, Transvaal, South Africa (proposed by R. T. A. Innes);
Rev. Arthur Edwin Brisco-Owen, M.A., The Rectory, Cholderton, Salisbury (proposed by the Rev. Charles D. P. Davies);
William Robert Bruce, Observatorio Magnetico, Pilar, Provincia de Córdoba, Argentine Republic (proposed by Ralph Copeland);

Lieut. Herbert Archer Edwards, R.N.R., Marine Office, Lagos, West Africa (proposed by Thomas Lewis);

Crawford M. Fleming, 14 North Kinver Road, Sydenham, S.E. (proposed by the Rev. D. Fleming);

William Edgar Geil, M.A., F.R.G.S., Doylestown, Pa., U.S.A., and 103 Pall Mall, S.W. (proposed by E. A. Reeves);

Thomas Henry Leale, A.K.C., Chaplain of Lambeth Infirmary, 65 Gaskarth Road, Balham Hill, S.W. (proposed by the Rev. F. B. Allison);

Lieut. Frederick William Mace, R.N.R., 2 Rutland Avenue, Sefton Park, Liverpool (proposed by Thomas Lewis);

William Ottway, Orion Works, Ealing, W. (proposed by A. Fowler);

Legh Richmond Powell, 10 Cranfield Road, Bexhill-on-Sea, Sussex (proposed by the Rev. F. B. Allison);

Rev. John Gardham Reed, Burlington Manse, South Road, Saffron Walden, Essex (proposed by the Rev. William Smith); and

Richard Frind Roberts, Chartered Accountant, Westcroft, Warlingham, Surrey (proposed by John Evershed).

One hundred and eighty-two presents were announced as having been received since the last meeting, including, amongst others:—

Miss A. M. Clerke, The System of the Stars, 2nd edition, presented by the author; Galileo, Opere, Edizione Nazionale, vol. 16, presented by the Italian Government; Dyson and Thackeray, New Reduction of Groombridge's Circumpolar Catalogue, presented by the Royal Observatory, Greenwich; G. W. Hill, collected mathematical works, presented by the author; Percival Lowell, Drawings of *Mars*, 1903, presented by the author; A. Marcuse, Handbuch der geographischen Ortsbestimmung, presented by the author; G. V. Schiaparelli, Astronomy in the Old Testament, presented by the Clarendon Press, Oxford.

Further charts of the Astrographic Chart of the Heavens, presented by the Royal Observatory, Greenwich, and the Paris Observatory; Loewy and Puiseux, Atlas Photographique de la Lune, fasc. 8, presented by the Paris Observatory.

Photographs of the seventh satellite of *Jupiter* taken at the Lick Observatory, presented by Professor Perrine; photographs of instruments and of the eclipse of 1905, presented by Rev. R. Killip; portrait (photograph) of Professor Loewy, presented by Professor Turner; photograph of the Lacaille Memorial at the Cape, presented by the South African Philosophical Society.

Small ring dial, presented by Mr. Wm. Ellis.

On the Secular Acceleration of the Earth's Orbital Motion.
By P. H. Cowell, M.A.

In a paper in the Supplementary Number of the *Monthly Notices* I showed that the ancient solar eclipses are satisfied by adopting the following secular terms:

1. In the distance of the Moon from the node $+4''\cdot4$
2. In the distance of the Moon from the Sun $+6''\cdot8$

and this month, in a separate paper, I show that these conclusions are supported by the Ptolemaic eclipses of the Moon recorded in the Almagest.

I then reasoned in the following way: The Sun must be assumed to have no sidereal secular acceleration. Therefore the sidereal secular acceleration of the Moon is $+6''\cdot8$ and of the node $+2''\cdot4$. On sending this result to Professor Newcomb, I received a reply alluding sarcastically to the "beautiful consistency . . . for a result contravening gravitational theory." Professor Newcomb is quite right, and I can only express my obligation to him for putting his arguments as forcibly as he did.

A day or two later the following modification of my argument suggested itself to me. Let us accept the value $+6''\cdot5$ as the sidereal secular acceleration of the node. It follows then from the ancient eclipses that $+10''\cdot9$ is the sidereal acceleration of the Moon and $+4''\cdot1$ that of the Sun.

This alteration of my conceptions only affects one part of the numerical calculations of my late paper on solar eclipses, and that part only to an unimportant degree. The formulæ I gave for the longitude of the node and the longitude of the Sun were intended to represent these longitudes measured from the equinox. They really represent the longitudes measured from an arbitrary departure point $+4''\cdot1T^2$ in advance of the equinox. With this change of definition no figure in the calculations requires alteration until we come to the corrections for parallax. Now the effect of substituting the true equinox for the departure point, which is about one-hundredth part of a radian away from it, can at the outside only affect the corrections for parallax by 1 per cent. or $20''$. Corrections of this magnitude are unimportant.

One other change is required. Instead of putting $\Delta V = T^2 s_L$, I should have put $\Delta(V-V') = T^2 . s_D$, where s_D is the correction to the assumed secular acceleration of the mean elongation.

A secular acceleration of the Earth's orbital motion does not "contravene gravitational theory," for it may be ascribed to the resistance of the ether. The sum of the kinetic and potential energies of the Earth in its orbit is equal to the potential energy it would have at a distance from the Sun equal to twice

its mean distance. A secular acceleration of $1''$ per century, or an increase per century of $2''$ in its centennial motion, or one part in 64,800,000, corresponds with a decrease of the mean distance of one part in 97,200,000. The loss of energy is therefore equal to the attraction of the Sun at double mean distance multiplied by twice the above fraction of the mean distance, which is equal to the attraction of the Sun at mean distance multiplied by the mean distance and divided by 194,400,000. If this loss of energy is sustained by the Earth in passing through 100 circumferences of its orbit, we conclude that the retarding force corresponding to a secular acceleration of a second is equal to the attraction of the Sun divided by $194,400,000 \times 2\pi \times 100$. For the secular acceleration found by me the divisor is 3×10^{10} nearly.

In order to obtain the theoretical secular acceleration of the node, Professor Newcomb's advice to me was: "Take Brown's mean motion of the node and differentiate it." The calculation is an easy one and goes as follows:

According to Professor Brown (*Monthly Notices*, vol. lxiv. p. 532) the centennial motion of the node contains the following terms, proportional to the square of the solar eccentricity:

$$-2546-57+8=2595''$$

From Professor Newcomb's tables of the Sun the solar eccentricity contains a factor

$$1-T\times 0{\cdot}002507-T^2 0{\cdot}00000752$$

T being measured in centuries from 1850, and its square therefore contains the factor

$$1-T\times 0{\cdot}005014-T\ 0{\cdot}00000875$$

and the mean motion of the node the variable part

$$+T\times 13''{\cdot}01+T^2\times 0''{\cdot}023$$

the longitude of the node (measured from a fixed point, and not a moving equinox) contains terms

$$+T^2\times 6''{\cdot}50+T^3\times 0''{\cdot}008$$

where the epoch is 1850, but may be taken as 1800 without sensible error.

By Mr. Crommelin's suggestion (I owe much to his many suggestions, that are based on a very wide acquaintance with astronomical literature) I have examined the transits of *Mercury* with a view to ascertaining whether the secular acceleration of the Earth is supported by them. I find on solving the equations of condition

secular acceleration of *Mercury*	... ...	0″·0
secular acceleration of Earth	... ...	3″·0

Details will shortly be published. It will be noted that the two entirely distinct methods of deducing a secular acceleration for the Earth are in close accordance. The zero result for *Mercury* is an argument against the cause being the resistance of the ether.

On the Ptolemaic Eclipses of the Moon recorded in the Almagest. By P. H. Cowell, M.A.

The nature of the changes in the secular terms of the lunar and solar tables now in use, that I am advocating, may be described as follows :—

1. A correction of −0″·6 to the secular term of the longitude of the node to bring it into accordance with Professor Brown's calculations.

2. A correction of −1″·6 to the secular term in the mean elongation.

3. A correction of +3″·0 to the secular term in the argument of latitude.

In order to see what light the ancient lunar eclipses throw upon these corrections it will be remarked :

1. The position of the equinox does not enter into a lunar eclipse. We can only hope, therefore, to obtain from lunar eclipses the relative positions of the Sun, Moon, and node, and we cannot hope to get the position of the equinox in addition.

2. The present *Nautical Almanac* is based upon Professor Newcomb's researches. Mr. Nevill has already shown (*Monthly Notices*, vol. xxxix.) that the result obtained by Professor Newcomb was the consequence of what Mr. Nevill deems the excessive weight given to the first eclipse of the series. The proper remark, therefore, to pass upon my second correction is that it is in accordance with Mr. Nevill. I do not pursue this branch of the inquiry, for observations considered by Professor Newcomb to have a probable error of 20 minutes of time or 600″ are not to be combined with observations of solar eclipses where a residual of 100″ would not be tolerated.

3. A correction of +3″·0 to the secular term of the argument of latitude combined with −1″·6 to the mean elongation produces +4″·6 in the distance of the Sun from the node, on which depends the magnitude of the eclipse. Professor Newcomb has not discussed the magnitudes of the eclipses. In this connection I have made the following calculations :

Taking as a starting-point Professor Newcomb's table on p. 41 of his *Researches*, I have added or subtracted one-tenth of the difference in longitude to the Moon's latitude. In this

way I have found the Moon's latitude at conjunction in longitude; and I may add that this process is far more accurate than the roundness of the number would suggest. From the latitude at conjunction I took off $\frac{1}{2}$ per cent., and so formed the quantity "Hansen's ∇," or nearest approach of the centre of Moon and centre of shadow according to Hansen's tables.

To calculate the effect of my corrections on ∇ I first calculated the effect of Newcomb's corrections to Hansen, and then that of my corrections to the present tables.

$$\Delta\nabla = \pm \tfrac{188}{200}\left[\tfrac{1}{11}\Delta F - \tfrac{1}{10}\Delta D\right]$$

where
$$\Delta F = -20''{\cdot}05T + 3''{\cdot}05T^2$$
$$\Delta D = -\ 1''{\cdot}44T - 1''{\cdot}44T^2$$

for my corrections,

and
$$\Delta F = \Delta D = -29''{\cdot}17T - 3''{\cdot}76T^2$$

for Newcomb's corrections.

It is clear that Newcomb's corrections to Hansen's ∇ are small, for Professor Newcomb did not alter the distance of the Sun from the node. My corrections to Newcomb's ∇ range from $5'{\cdot}1$ to $2'{\cdot}4$.

The radius of shadow is calculated from the formula $p + p' - \sigma$, when p, σ are given in the table on p. 41 of the *Researches* and p' is taken as $9''$. Lastly, the radius of the Moon was taken as $0{\cdot}273 \times p$ and the magnitude of the eclipse as $\dfrac{\Sigma + \mu - |\nabla|}{2\mu}$, $|\nabla|$ of course being taken positively.

In the following table the results are tabulated.

Newcomb's Eclipse No.	Date.	Hansen's ∇	$\Delta\nabla$ N.	$\Delta\nabla$ C.	Radius of Shadow Σ	Magnitude of Eclipse. N.	C.	O.
		′	′	′	′			
1	−720	+ 6·8	+0·2	+5·1	39·9	1·58	1·41	total
2	−719	+47·8	+0·2	+5·1	38·0	0·16	0·00	3 digits = 0·25
3	−719	−43·5	−0·2	−5·1	45·3	0·55	0·40	more than half
4	−620	+51·8	−0·2	−4·8	38·3	0·05	0·21	0·25
5	−522	−41·1	+0·2	+4·4	38·5	0·45	0·60	0·5
6	−501	+49·8	−0·2	−4·4	37·6	0·09	0·24	0·25
7	−490	+57·7	−0·2	−4·4	42·1	0·01	0·15	2 digits = 0·17
8*	−382	−56·0	+0·2	+3·9	43·8	0·13	0·25	small
9	−381	+44·2	−0·2	−3·9	38·6	0·31	0·44	—
10	−381	−15·4	+0·2	+3·9	45·2	1·40	1·52	total

* In eclipse No. 8 Professor Newcomb has pointed out that the Moon with his corrections had already set. I regret to say that a similar remark applies to my corrections.

Newcomb's Eclipse No.	Date.	Hansen's ∇	Δ∇		Radius of Shadow Σ	Magnitude of Eclipse.		
			N.	G.		N.	G.	O.
		′	′	′	′			
11	−200	+35·2	−0·1	−3·4	39·5	0·67	0·78	partial
12	−199	+13·4	+0·1	+3·4	42·5	1·41	1·30	total
13	−199	− 6·6	−0·1	−3·4	42·6	1·62	1·51	total
14	−173	−40·9	−0·1	−3·3	45·4	0·64	0·53	7 digits = 0·58
15	−140	+52·9	+0·1	+3·2	45·2	0·27	0·17	3 digits = 0·25
16	+125	+55·7	−0·1	−2·4	42·6	0·09	0·17	0·17
17	+133	−24·1	+0·1	+2·4	39·1	1·00	1·08	total
18*	+134	−28·7	−0·1	−2·4	39·5	0·85	0·77	[0·33]
19	+136	−48·5	+0·1	+2·4	44·6	0·38	0·46	0·50

It will be evident from the explanation, but it should be stated in close proximity to the table, that the columns headed "N." are not copied from Professor Newcomb, but are computations of my own to correspond with "Newcomb's corrections."

This table on the whole exhibits some slight evidence in favour of my correction to the distance between the Sun and the Moon's node. In fact, the error only amounts to 0·1 in the case of the first two eclipses. It will be noticed that in the first three eclipses we find the phrase: "is recorded as having occurred." In the other eclipses we find the more positive assertion: "occurred."

Observation of the Partial Eclipse of the Sun, 1905 *August* 29–30, *at the Radcliffe Observatory, Oxford.*

(*Communicated by Dr. Arthur A. Rambaut, F.R.S., Radcliffe Observer.*)

The time of first contact was well observed by Mr. Wickham, with a telescope which is permanently attached to the mounting of the 18-inch and 24-inch telescopes. The object-glass of this instrument is of 7 inches aperture, and its focal length is nearly 10 feet; the eyepiece employed was an ordinary solar diagonal of power 125.

Clouds had for some time prevailed, but fortunately for a short interval before contact the obscuration diminished, until only a very thin haze remained; through this the surface markings of the Sun's disc were neatly and clearly seen, and the limb was steady and sharply defined.

The first trace of indentation by the advancing limb of the Moon was easily detected, and the time registered by means of

* In eclipse No. 18 the observed magnitude was perhaps 0·67 and an error of copying has occurred.

the electric chronograph. The instant thus recorded, when expressed in Greenwich mean time, was

$$23^h\ 47^m\ 3^s{\cdot}8$$

which is practically identical with the time (predicted to the decimal of a minute) in the *Nautical Almanac*, viz.

$$23^h\ 47^m{\cdot}1$$

By watching the rate of progress of the indentation for some seconds the observer estimated that external geometrical contact took place 2 seconds earlier than the time registered. The Moon's motion was rapid.

Broken clouds soon supervened, and ultimately the sky became thickly overcast, the final contact being invisible.

Radcliffe Observatory, Oxford:
1905 *November* 6.

Observations of Comet d 1902 from Photographs taken with the 30-inch Reflector of the Thompson Equatorial at the Royal Observatory, Greenwich.

(*Communicated by the Astronomer Royal.*)

The following positions of Comet *d* 1902 are obtained from photographs with the 30-inch reflector. As a rule there were two images on each plate, and the exposures varied from 10^m to 20^m. The plates were measured in the Astrographic Micrometer. Four reference stars were taken in each case, situated as symmetrically as possible about the comet. The positions of the reference stars were derived from the Catalogues of the *Astronomische Gesellschaft.*

Date and G.M.T.				Apparent R.A.			Apparent Dec.			Log. Δ.	Corr. for Parallax.	
											R.A.	Dec.
1902.	h	m	s	h	m	s	°	′	″		s	″
Dec. 29	12	2	54	7	4	32·07	3	16	43·6	0·2917	−0·03	+3·3
30	12	36	32	7	3	49·67	3	32	55·3	0·2903	+ ·01	+3·3
31	11	59	17	7	3	8·62	3	48	37·6	0·2889	− ·02	+3·3
1903.												
Jan. 2	11	33	4	7	1	43·99	4	21	19·9	0·2866	− ·04	+3·3
3	10	39	33	7	1	2·45	4	37	34·5	0·2855	− ·07	+3·3
7	10	31	23	6	58	7·37	5	47	15·5	0·2818	− ·07	+3·3
7	10	57	55	6	58	6·52	5	47	35·8	0·2818	− ·05	+3·3
8	11	34	30	6	57	21·20	6	6	3·4	0·2809	− ·01	+3·3
15	11	29	1	6	52	14·79	8	17	3·9	0·2779	+ ·01	+3·2

Date and G.M.T.		Apparent R.A.	Apparent Dec.	Log. Δ.	Corr. for Parallax. R.A.	Corr. for Parallax. Dec.
1903.	h m s	h m s	° ′ ″		s	″
Jan. 15	11 47 49	6 52 14·30	8 17 19·4	0·2779	+ ·03	+ 3·2
25	10 20 57	6 45 33·30	11 33 26·3	0·2797	− ·01	+ 2·9
28	9 19 23	6 43 48·56	12 32 40·8	0·2816	− ·05	+ 2·9
Feb. 1	10 27 10	6 41 40·07	13 53 34·1	c·2852	+ ·03	+ 2·8
2	9 36 23	6 41 12·17	14 12 46·8	0·2901	− ·01	+ 2·7
16	10 32 39	6 36 51·23	18 42 17·0	0·3110	+ ·08	+ 2·4
17	9 38 2	6 36 44·11	18 59 49·9	0·3128	+ ·04	+ 2·3
18	7 14 24	6 36 38·92	19 16 7·5	0·3147	− ·07	+ 2·3
21	9 33 49	6 36 30·35	20 11 9·0	0·3205	+ ·05	+ 2·2
23	8 10 18	6 36 33·03	20 44 51·0	0·3247	0·0	+ 2·1
25	7 19 46	6 36 42·09	21 18 15·7	0·3288	− ·05	+ 2·1
26	7 21 7	6 36 49·06	21 35 0·3	0·3310	− ·04	+ 2·1
28	7 50 58	6 37 8·33	22 8 16·1	0·3353	− ·01	+ 2·0
Mar. 1	7 22 7	6 37 20·09	22 24 8·0	0·3374	− ·03	+ 2·0
3	8 44 46	6 37 49·92	22 56 50·2	0·3419	+ ·04	+ 1·9
4	7 50 16	6 38 6·33	23 11 50·8	0·3442	·00	+ 1·9
6	7 14 32	6 38 44·82	23 42 7·2	0·3487	− ·02	+ 1·8
6	7 34 14	6 38 45·00	23 42 19·0	0·3487	− ·01	+ 1·8
11	7 37 56	6 40 50·79	24 55 40·7	0·3603	+ ·01	+ 1·7
11	7 57 8	6 40 51·22	24 55 51·6	0·3603	+ ·02	+ 1·7
12	8 12 56	6 41 21·40	25 10 5·9	0·3627	+ ·04	+ 1·7
12	8 38 52	6 41 21·99	25 10 20·4	0·3627	+ ·06	+ 1·7
13	7 24 39	6 41 51·91	25 23 30·7	0·3650	·00	+ 1·7
13	7 47 20	6 41 52·38	25 23 44·7	0·3650	+ ·02	+ 1·7
15	7 27 35	6 42 59·49	25 50 45·9	0·3698	+ ·01	+ 1·6
16	9 12 37	6 43 38·19	26 5 2·5	0·3722	+ ·09	+ 1·7
21	7 50 30	6 46 59·06	27 8 1·4	0·3840	+ ·04	+ 1·5

Further details of the observations will be given in the Greenwich Volume for 1904.

Observations of the Satellite of Neptune from Photographs taken at the Royal Observatory, Greenwich, between 1904 *November* 11 *and* 1905 *April* 15.

(*Communicated by the Astronomer Royal.*)

The following measures of position-angle and distance of *Neptune's* satellite were made from photographs taken with the 26-inch refractor of the Thompson Equatorial. The occulting shutter was used, as in previous years. The photographs were taken by Messrs. Davidson, Edney, or Melotte, and were measured in a position micrometer in direct and reversed positions by Messrs. Edney and Burkett. The tabular positions with which comparison is made were computed from the data given in the *Connaissance des Temps*, based on Dr. Hermann Struve's elements, the eccentricity of the orbit being neglected.

A discussion of these residuals gives the following differences in the sense Tabular–Observed to Dr. Hermann Struve's elements.

$$du = -0^{\circ}{\cdot}72. \quad dN = -0^{\circ}{\cdot}89. \quad dI = -0^{\circ}{\cdot}27. \quad da = +''{\cdot}086\,;$$

giving for the epoch 1905·1

$$a = 16''{\cdot}185. \quad N = 188^{\circ}{\cdot}26. \quad I = 117^{\circ}{\cdot}14.$$

NEPTUNE AND SATELLITE.

Position-angle and Distance from Photographs taken with the 26-inch Refractor.

Date and G.M.T.		h	m	s	Position-angle. Observed.	Tabular.	T—O.	Distance. Observed.	Tabular.	T—O.
1904.	d				°	°	°	"	"	"
Nov.	11	12	1	38	315·77	317·91	+2·14	12·47	12·82	+0·35
	11	12	37	34	315·66	316·23	+0·57	12·76	12·97	+ ·21
	14	12	52	18	131·53	131·60	+0·07	13·20	13·43	+ ·23
	14	13	25	32	128·86	130·18	+1·32	13·56	13·57	+ ·01
	15	12	3	45	84·89	86·80	+1·91	16·20	16·68	+ ·48
	22	11	45	23	20·87	23·73	+2·86	11·28	11·49	+ ·21
	22	12	19	12	22·97	21·71	−1·26	11·46	11·41	− ·05*
	22	13	3	38	19·37	19·00	−0·37	11·70	11·31	− ·39
	22	13	33	54	15·77	17·13	+1·36	11·57	11·24	− ·33
Dec.	5	12	14	20	288·13	289·97	+1·84	15·39	15·77	+ ·38
	5	12	42	16	288·00	289·09	+1·09	15·48	15·85	+ ·37
	5	13	7	49	288·02	288·28	+0·26	15·78	15·93	+ ·15
	7	11	7	55	178·29	178·25	−0·04	10·80	11·06	+ ·26
	20	10	33	31	98·63	99·49	+0·86	16·56	16·62	+ ·06

* Neptune on edge of occulting shutter.

Date and G.M.T.					Position-angle.			Distance.		
					Observed.	Tabular.	T—O.	Observed.	Tabular.	T—O.
1905.	d	h	m	s	°	°	°	"	"	"
Jan.	9	9	52	4	307·67	308·77	+1·10	13·45	13·64	+ ·19
	9	10	24	28	307·20	307·40	+0·20	13·53	13·78	+ ·25
	10	9	19	11	263·01	263·91	+0·90	16·86	16·79	− ·07
	10	9	49	47	262·79	263·05	+0·26	16·57	16·76	+ ·19
	17	10	14	18	194·26	195·24	+0·98	11·41	11·29	− ·12
	17	10	47	8	191·11	193·19	+2·08	11·03	11·23	+ ·20
	25	10	10	50	68·94	69·07	+0·13	15·67	15·67	·00
	25	10	40	1	67·77	68·13	+0·36	15·62	15·57	− ·05
	25	11	6	48	66·98	67·25	+0·27	15·50	15·48	− ·02
Feb.	2	10	18	9	282·74	282·77	+0·03	15·97	16·17	+ ·20
	2	10	55	15	281·21	281·66	+0·45	16·11	16·26	+ ·15
	6	10	32	56	54·26	55·80	+1·54	13·83	14·21	+ ·38
	6	11	9	11	53·42	54·37	+0·95	13·64	14·05	+ ·41
	16	8	39	58	146·60	146·55	−0·05	11·62	11·91	+ ·29
	17	11	21	31	86·69	88·25	+1·56	17·08	16·69	− ·39
	17	11	46	39	85·91	87·55	+1·64	16·98	16·69	− ·29
Mar.	2	8	50	23	28·90	27·50	−1·40	11·35	11·66	+ ·31*
	2	9	28	6	27·02	25·36	−1·66	11·26	11·54	+ ·28*
	2	10	1	57	24·15	23·40	−0·75	11·59	11·44	− ·15
	3	9	8	11	301·94	304·28	+2·34	13·89	13·69	− ·20
	3	9	35	53	303·06	303·16	+0·10	13·25	13·81	+ ·56
	3	10	12	7	301·64	301·72	+0·08	13·90	13·96	+ ·06
	9	9	19	26	295·76	296·18	+0·42	14·18	14·51	+ ·33
	17	7	19	11	183·23	186·22	+2·99	10·50	10·80	+ ·30
	17	7	51	42	183·71	184·12	+0·41	10·60	10·77	+ ·17
	21	7	31	1	287·84	288·64	+0·80	14·99	15·21	+ ·22
	21	8	2	56	286·32	287·62	+1·30	15·38	15·31	− ·07
	21	8	27	51	285·32	286·82	+1·50	14·76	15·38	+ ·62
	21	8	58	46	285·38	285·85	+0·47	14·94	15·48	+ ·54
	22	7	47	15	245·67	245·82	+0·15	14·96	15·01	+ ·05
	22	8	12	22	243·60	244·98	+1·38	14·72	14·92	+ ·20
	22	8	55	5	242·85	243·53	+0·68	14·71	14·77	+ ·06
	22	9	18	30	242·85	242·73	−0·12	14·78	14·68	− ·10
	23	7	30	56	173·00	173·99	+0·99	11·00	10·73	− ·27
	23	8	4	31	170·89	171·81	+0·92	10·72	10·75	+ ·03
	24	7	48	7	104·60	105·30	+0·70	15·32	15·50	+ ·18
	24	8	26	36	103·21	104·12	+0·91	15·57	15·61	+ ·04

* Neptune on edge of occulting shutter.

Date and G.M.T.					Position-angle.			Distance.		
					Observed.	Tabular.	T−O.	Observed.	Tabular.	T−O.
1905.	d	h	m	s	°	°	°	″	″	″
Mar.	27	7	48	11	281·98	282·60	+0·62	15·78	15·71	− ·07
	27	8	21	49	280·98	281·60	+0·62	15·91	15·79	− ·12
Apr.	6	8	11	8	47·09	48·30	+1·21	13·10	13·04	− ·06
	12	9	16	18	36·43	36·96	+0·53	12·00	12·01	+ ·01
	12	9	41	23	35·72	35·68	−0·04	11·95	11·92	− ·03
	15	9	20	56	212·30	212·11	−0·19	11·19	11·65	+ ·45

Observations of Jupiter's Sixth and Seventh Satellites from Photographs taken with the 30-inch Reflector of the Thompson Equatorial at the Royal Observatory, Greenwich.

(*Communicated by the Astronomer Royal.*)

The photographs were taken by Mr. Melotte, Mr. Davidson, or Mr. Edney. The measures of distance and position-angle from *Jupiter* are to be considered as merely provisional pending more complete measurements by the help of reference stars. The over-exposed image of *Jupiter* gave a reversed image in its centre suitable for measurement.

For more accurate measurement it is proposed to find the positions of the satellite in each case relatively to three or four faint comparison stars round it—the positions of these comparison stars relatively to 9 mag. reference stars being obtained from photographs with the Astrographic telescope, where the field sensibly free from distortion is much larger. The position of *Jupiter* will be determined from similar photographs with shorter exposures, the same stars being used as reference stars.

The provisional measures given below are not corrected for refraction and aberration. A comparison is given with Mr. F. E. Ross's Ephemerides, *A.N.* 4042 and L.O.B. No. 82.

Observations of Jupiter and Satellite VI.

Plate No.	Date.		G.M.T.		*p*.		*s*.		Tab.−Obs. *p*.	Tab.−Obs. *s*.	Exposure.
	1905.		h	m	°	′	′	″	°	′	m
2028	Aug.	23	13	30	311	9	25	30	...	...	30
2029		23	14	23	310	45	25	33	...	...	31
2038	Sept.	3	15	17	290	51	36	59	+4·8	− 0·5	40
2047		7	13	26	286	54	40	52	3·9	1·0	60
2048		7	15	32	286	48	40	54	4·0	1·0	55
2050		8	12	56	285	54	41	43	3·7	0·9	30
2054		12	14	37	281	29	45	16	4·0	1·5	20
2055		12	15	5	281	26	45	17	+4·0	−1·5	20

Plate No.	Date.	G.M.T.	p.	s.	Tab.—Obs. p.	Tab.—Obs. s.	Exposure.
	1905.	h m	° ′	′ ″	°	′	m
2056	Sept. 12	15 42	281 32	45 17	+4·0	− 1·5	30
2068	30	12 17	267 34	54 53	3·2	0·6	60
2070	Oct. 4	12 25	264 51	55 29	2·8	0·5	40
2072	4	16 38	264 41	55 31	2·9	0·5	39
2074	5	11 52	264 3	55 33	2·7	0·5	30
2075	5	13 7	264 10	55 34	2·6	0·6	59
2077	6	11 16	263 34	55 34	2·4	− 0·6	26
2079	21	10 55	251 38	51 54	1·9	+ 0·1	45
2080	21	11 54	251 37	51 53	1·9	0·1	45
2081	22	10 46	250 40	51 24	1·8	0·2	40
2082	22	12 4	250 44	51 24	1·8	0·2	75
2086	25	10 47	248 0	49 47	1·5	0·3	30
2087	25	11 47	248 0	49 45	1·5	0·3	60
2089 {	27	10 17	246 10	48 34	1·3	0·3	40
	27	10 58	246 10	48 33	1·3	0·3	29
2091	29	9 47	244 11	47 19	1·3	0·3	30
2092	29	10 20	244 8	47 16	1·3	0·3	25
2093	29	12 19	244 1	47 16	1·3	0·3	177
2094	29	14 17	243 59	47 9	1·3	0·3	17
2096 {	31	10 24	241 42	45 54	1·3	0·1	25
	31	10 48	241 42	45 54	1·3	0·1	20
2097	31	12 4	241 31	45 51	1·3	+ 0·1	84
2098	Nov. 3	9 49	238 9	43 46	1·3	− 0·2	30
2100	3	11 45	237 58	43 43	1·3	0·1	54
2104	6	10 19	233 51	41 32	1·2	0·3	15
2105	6	10 48	233 50	41 31	1·2	0·3	15
2106	6	11 50	233 53	41 27	1·2	0·3	70
2110	7	14 12	232 19	40 38	1·4	0·3	15
2111	7	15 14	232 9	40 33	+1·3	− 0·3	90

Observations of Jupiter and Satellite VII.

Plate No.	Date	G.M.T.	p.	s.	Tab.—Obs. p.	Tab.—Obs. s.	Exposure
	1905.	h m	° ′	′ ″	°	′	m
2082	Oct. 22	12 4	286 15	41 55	+1·0	+ 5·6	75
2093	29	12 19	286 29	31 44	0·3	7·6	177
2094	29	14 17	286 30	31 32	+0·3	7·6	17
2097	31	12 4	286 30	28 25	−0·5	8·1	84
2100	Nov. 3	11 45	286 47	23 21	1·9	8·9	54
2106	6	11 50	287 15	18 4	3·0	10·0	70
2111	7	15 14	287 46	15 54	−3·7	+10·8	90

Observations of Phenomena of Jupiter's Satellites at Windsor, New South Wales, in the years 1900 *and* 1902. By John Tebbutt.

Day of Observation.	Satellite.	Phenomenon.	Phase.	Mag. Power.	G.M.T. of Observation. h m s	Mean Time of *Nautical Almanac.* h m s
1900.						
June 30	I.	Tr. Egr.	Int. contact	168	21 26 29	
30	I.	"	Bisection	"	21 28 39	21 31
30	I.	"	Ext. contact	"	21 30 54	
July 1	I.	Ecl. R.	First seen	74	19 32 48	19 33 17
1	I.	"	Full brightness	"	19 35 42	
13	III.	"	First seen	"	20 48 24	20 49 29
13	II.	Tr. Ingr.	Ext. contact	168	22 2 22	
13	II.	"	Bisection	"	22 4 47	21 58
13	II.	"	Int. contact	"	22 7 7	
15	I.	Occ. D.	First contact	"	20 9 2	
15	I.	"	Bisection	"	20 11 7	20 10
15	I.	"	Last seen	"	20 12 52	
15	I.	Ecl. R.	First seen	74	23 21 39	23 22 24
15	I.	"	Full brightness	"	23 25 14	
Sept. 17	II.	"	First seen	"	20 34 4	20 37 2
17	II.	"	Full brightness	"	20 38 59	
Oct. 1	I.	"	First seen	"	20 24 35	20 25 5
1	I.	"	Full brightness	"	20 28 9	
1902.						
Sept. 14	IV.	Occ. D.	First contact	168	23 9 39	
14	IV.	"	Bisection	"	23 13 38	23 21
14	IV.	"	Last seen	"	23 17 33	
14	I.	"	First contact	"	23 14 8	
14	I.	"	Bisection	"	23 15 53	23 16 0
14	I.	"	Last seen	"	23 18 22	
16	I.	Ecl. R.	First seen	74	20 58 30	20 58 50
16	I.	"	Full brightness	"	21 0 18	
19	II.	"	First seen	"	23 47 21	23 48 7
19	II.	"	Full brightness	"	23 50 23	
30	I.	Occ. D.	First contact	138	21 19 49	
30	I.	"	Bisection	"	21 22 9	21 22
30	I.	"	Last seen	"	21 23 58	
Oct. 4	III.	Tr. Ingr.	Ext. contact	"	22 18 1	
4	III.	"	Bisection	"	22 21 40	22 20
4	III.	"	Int. contact	"	22 25 29	
5	II	Tr. Egr.	Int. contact	"	21 41 0	

Day of Observation.	Satellite.	Phenomenon.	Phase.	Mag. Power.	G.M.T. of Observation. h m s	Mean Time of *Nautical Almanac.* h m s
1902.						
Oct. 5	II.	Tr. Egr.	Bisection	138	21 44 49	21 46
5	II.	„	Ext. contact	„	21 48 34	
7	I.	Occ. D.	First contact	168	23 11 11	
7	I.	„	Bisection	„	23 13 31	23 13
7	I.	„	Last seen	„	23 15 20	
8	I.	Tr. Ingr.	Ext. contact	„	20 21 7	
8	I.	„	Bisection	„	20 23 12	20 21
8	I.	„	Int. contact	„	20 25 7	
8	III.	Ecl. R.	First seen	„	20 56 9	20 58 48
8	I.	Tr. Egr.	Int. contact	„	22 36 59	
8	I.	„	Bisection	„	22 38 4	22 41
8	I.	„	Ext. contact	„	22 40 54	
9	I.	Ecl. R.	First seen	74	21 13 35	21 13 35
12	II.	Tr. Ingr.	Ext. contact	168	21 21 53	
12	II.	„	Bisection	„	21 23 33	21 19
12	II.	„	Int. contact	„	21 25 43	
13	II.	Tr. Egr.	Int. contact	„	0 11 0	
13	II.	„	Bisection	„	0 13 55	0 15
13	II.	„	Ext. contact	„	0 17 4	
14	II.	Ecl. R.	First seen	74	20 58 30	20 59 20
14	II.	„	Full brightness	„	21 3 4	
15	III.	Ecl. D.	Began to fade	168	21 21 14	
15	III.	„	Last seen	„	21 26 37	21 27 12
15	I.	Tr. Ingr.	Ext. contact	„	22 12 45	
15	I.	„	Bisection	„	22 14 25	22 13
15	I.	„	Int. contact	„	22 16 6	
16	I.	Tr. Egr.	Int. contact	„	0 29 7	
16	I.	„	Bisection	„	0 30 52	0 34
16	I.	„	Ext. contact	„	0 33 6	
16	III.	Ecl. R.	First seen	„	0 57 30	1 0 22
16	III.	„	Full brightness	„	1 3 51	
16	I.	„	First seen	74	23 8 22	23 8 56
16	I.	„	Full brightness	„	23 11 38	
19	II.	Tr. Ingr.	Ext. contact	168	23 53 57	
19	II.	„	Bisection	„	23 55 36	23 50
19	II.	„	Int. contact	„	23 58 1	
21	II.	Ecl. R.	First seen	74	23 37 3	23 37 10
21	II	„	Full brightness	„	23 40 13	
Dec. 1	I.	„	First seen	43	23 38 14	23 38 18
1	I.	„	Full brightness	„	23 41 39	

Notes.

1900.
June 30. Good definition and observations.
July 1. Observation in partial twilight and unsatisfactory.
13. Beautifully clear sky and good definition at the eclipse, but satellite detected rather late. Poor definition at the transit.
15. Sky beautifully clear, and definition good throughout. Observations good.
Sept. 17. Sky beautifully clear and observation good, but the twilight had not disappeared.
Oct. 1. Sky beautifully clear, and definition good, but twilight strong. Satellite detected rather late.

1902.
Sept. 14. Sky beautifully clear and definition pretty good. The contrast between the brightness and colour of the satellites was remarkable. While the first was very bright and of a yellowish colour up to contact, the fourth was remarkably dull and of a bluish tint.
16. Sky beautifully clear and definition pretty good, but full Moon present. Satellite detected about a second late.
19. Sky clear and definition good. The satellite was suspected a little earlier than the recorded time.
30. Sky hazy, but images steady and pretty well defined.
Oct. 4–5. Beautifully clear, definition good, and observations satisfactory. As the satellite would pass a little north of the centre of the disc I expected the usual dark transit, and was not disappointed. The satellite was seen with great difficulty as a bright spot in contact with the south edge of the great north equatorial belt at $22^h\ 38^m\ 7^s$. It then became invisible, and continued so till $22^h\ 49^m\ 35^s$, when it was suspected as a faint hazy spot. It gradually grew darker till the time of mid-transit, $0^h\ 15^m\ 21^s$, when it was very dark and well defined, but not so dark as the shadow in transit. I have seen the satellite darker.
5. Satellite faint at first contact, definition good.
7. Images steady and well defined, and observations good.
8. Sky beautifully clear throughout; definition fair, but images tumulous at transit ingress. Definition fair and images steady at eclipse, but Moon present. When about one third of its way across the disc, satellite I. was seen as a faint hazy spot; it grew somewhat darker till $22^h\ 7^m\ 50^s$, and ceased to be visible at $22^h\ 18^m\ 33^s$. The definition at egress was not so good, and the internal contact was noted rather late.
9. Sky beautifully clear.
12–13. Images steady and well defined, particularly at ingress. The satellite was seen as a bright spot till $21^h\ 52^m\ 28^s$, when it became invisible. At $0^h\ 9^m\ 50^s$ it was again seen as a bright spot. No trace could be seen of it at mid-transit.
14. Sky beautifully clear, but Moon very bright; images steady and well defined.
15–16. Beautifully clear throughout, but full Moon present. The conjunction of satellites I. and III. in the plane of their motion occurred about $21^h\ 17^m\ 29^s$, but I think the observation was rather late; they appeared to be just in contact. The steadiness and definition at transit ingress were satisfactory. Satellite I. was seen as a bright spot till about $22^h\ 36^m\ 17^s$. At $22^h\ 59^m\ 43^s$ it became visible as a hazy spot. It was again invisible at $0^h\ 0^m\ 32^s$. Observation of the internal contact at egress was difficult owing to the faintness of the satellite, and the recorded time was rather late. Satellite III. suspected at $0^h\ 57^m\ 30^s$, but I was certain of it $28\frac{1}{2}$ seconds later. This satellite appeared bluish about three minutes before full brightness.

Oct. 16. Sky clear near planet and definition good at reappearance of satellite I. The satellite was suspected at the recorded time, but I was certain of it 12½ seconds later.
19. Steadiness and definition very satisfactory.
21. Images steady and well defined, but sky very hazy.
Dec. 1. Sky hazy near planet, which was rather low for good observation.

The observations of December 1 were made with the $4\frac{1}{2}$-inch equatorial, and all the others with the 8-inch instrument. An occulting-bar was not employed in the eclipse observations, and the observations of full brightness are only rough approximations. The times given throughout are the Windsor mean times diminished by $10^h\ 3^m\ 20^s{\cdot}5$, and entered to the nearest second. This communication contains all the phenomena of *Jupiter's* satellites observed here since those published for 1898 and 1899 in vol. lx. of the *Monthly Notices.*

Observatory, Peninsula, Windsor, N. S. Wales:
1905 *October* 1.

Results of Micrometer Measures of Double Stars made with the 28-inch Refractor at the Royal Observatory, Greenwich, in the year 1904.

(*Communicated by the Astronomer Royal.*)

The measures were made with a bifilar position-micrometer on the 28-inch refractor, focal length 28 feet. The power generally employed was 670, but when definition permitted a power of 1120 was employed for observing very close pairs. When bright stars were observed a blue glass shade was usually employed to diminish the light and irradiation. The observations were made in variously coloured fields or in a dark field with illuminated wires. The initials in the last column are those of the observers, viz.:

L. Mr. Lewis. H. F. Mr. Furner.
W. B. Mr. Bowyer.

On nights when the definition was not sufficiently good for measuring stars in the ordinary Working List, the time was spent in measuring stars from a Supplementary List, made up of Struve stars which have been neglected, or which require periodical observation at intervals of ten years or so, and of miscellaneous stars in which the companion is very faint. As measures of such pairs are not of immediate interest, a list only of the stars observed is given here, the publication of the measures, as well as of the individual results of the observations

of the other stars, being reserved for the volume of *Greenwich Observations* for 1904.

In general the present list of measures is confined to stars of which the separation is under 4″, or which show orbital movement.

Stars in the Supplementary List observed in 1904.

Struve Stars.

Σ 183	Σ 899	Σ 1375	Σ 2178	Σ 2395	Σ 2769
200	929	1421	2184	2428	2792
214	953	1443	2193	2429	2814
224	958	1459	2194	2450	2829
240	986	1555 A.C.	2198	2587	2834
260	1018	1835	2201	2615	2841
273	1027	2001	2225	2618	2861
412	1066	2006 A.C.	2225ª	2621	2876
420	1174	2014	2226	2622	2895
444	1184	2016	2237	2628	2908
449	1200	2029	2255	2631	2910
450	1204	2030	2263	2633	2931
452	1212	2043	2265	2634	2941
458	1218	2072	2266	2635	2945
524	1220	2076	2283	2639	2949
529	1237	2079	2304	2663	2957
582	1239	2085	2313	2664	2967
603	1246	2087	2319	2680	2978
616	1251	2102	2321	2691	3006
625	1259	2103	2322	2704 A.C.	3007
662	1262	2135	2329	2704 A.D.	3021
669	1274	2147	2333	2718	3024
674	1278	2164	2335	2725	3040
680	1288	2172	2336	2731	3042
683	1293	2174	2341	2747	3043
706	1297	2175	2345	2759	3044
718	1301	2176	2351	2760	3048
877	1321	2177	2385	2761	3058

Otto Struve Stars.

OΣ 230, 304 and 444.

Hough Stars.

Ho. 67, 84, 252, 259, 377, 551, 557, 582.

Burnham, 45.

Micrometric Observations of Double Stars at the Royal Observatory, Greenwich.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1904.	Obs.
	h m	° ′	°	″				
Σ 3060... ...	0 1	72 29	121·6	3·72	2	8·5 8·7	·946	W.B.
A.G. 56 ...	0 12	68 47	132·2	2·11	1	8·9 9·4	·841	W B
Σ 25	0 14	74 34	191·4	1·44	1	8·5 8·5	·841	W.B.
Σ 67	0 47	79 56	358·7	1·93	1	8·3 9·0	·841	W.B.
Σ 73	0 50	66 55	24·4	0·95	3	6·2 6·8	·591	W.B.
			25·7	0·81	1	...	·865	H.F.
Σ 137	1 30	59 14	88·3	3·38	1	8·2 9·0	·088	W.B.
Σ 138	1 31	82 52	40·1	1·52	2	7·3 7·3	·882	W.B.
			37·1	1·28	1	...	·865	H.F.
Σ 140	1 33	49 25	175·1	3·54	2	8·5 9·2	·091	W.B.
Σ 178	1 47	79 41	199·7	3·28	1	7·8 7·8	·865	H.F.
β 260	1 48	75 3	235·8	0·75	1	8 3 8·9	·865	H.F.
Σ 194	1 54	65 39	269·9	1·23	1	8·0 8·3	·969	W.B.
OΣ 38	1 58	48 9	113·4	...	1	5·0 6·2	·123	L.
Σ 205	1 58	48 9	63·1	10·21	1	3·0 5·0	·123	L.
Σ 208	1 58	64 33	87·5	0·55	2	6·2 8·4	·529	W.B.
			79·0	0·71	1	...	·096	H.F.
Σ 226	2 7	66 30	247·0	2·22	1	7·8 9·7	·088	W.B.
Σ 269	2 22	60 34	340·6	1·95	1	7·5 9·8	·969	W.B.
Σ 305	2 42	71 3	314·9	3·03	4	7·3 8·2	·031	W.B.
			314·7	2·93	1	...	·096	H.F.
Σ 333	2 54	69 4	201·6	1·23	3	5·7 6·0	·023	W.B.
			207·0	1·48	1	...	·096	H.F.
Σ 346	3 0	65 8	88·4	0·45	2	6·0 6·0	·504	W B.
			94·7	0·54	1	...	·096	H.F.
A.C. ...			356·8	5·22	1	6·0 10·8	·096	H.F.
Σ 352	3 3	54 56	359·1	3·64	2	8·2 10·3	·178	W.B.
Σ 375	3 15	66 40	315·0	2·41	1	8·0 10·1	·131	W.B.
Σ 384	3 20	30 27	269·2	1·82	1	7·8 9·0	·192	W.B.
Σ 389	3 22	30 59	59·4	2·65	1	7·0 8·0	·192	W.B.
Σ 395	3 23	61 17	104·0	1·83	1	8·5 10·0	·129	L.
β 533	3 29	58 39	53·8	0·57	1	7·5 7·5	·129	L.
Σ 425	3 34	56 10	271·1	2·42	2	7·3 7·3	·039	W.B.
β 535	3 38	58 2	55·8	1·00	1	3·8 8·5	·129	L.
Σ 438	3 38	67 35	242·7	1·86	1	8·5 10·5	·129	L.
Σ 442	3 39	67 36	259·8	2·97	1	9·0 9·5	·129	L.
β 537	3 41	65 28	201·2	0·86	1	8·4 9·8	·126	L.

Star's Name.	R.A. 1900. h m	N.P.D. 1900. ° ′	Position Angle. °	Distance. ″	No. of Nights.	Mags.	Epoch 1903.	Obs.
β 537	3 41	65 28	188·0	1·05	1	8·4 9·8	·131	W.B.
Ho. 324 ...	3 43	75 18	337·9	0·64	1	8·1 8·3	·022	W.B.
Σ 457	3 44	67 37	103·0	1·12	1	8·8 8·8	·123	L.
Hu. 24... ...	3 52	78 48	273·8	1·10	1	8·5 11·3	·123	L.
Hu. 25... ...	3 53	78 10	321·6	0·75	1	8·6 9·1	·123	L.
Σ 483	3 57	50 46	234·0	0·43	1	7·4 9·2	·129	L.
			239·2	0·57	1	...	·131	W.B.
Σ 522	4 15	38 38	210·0	1·55	1	8·5 8·5	·164	W.B.
OΣ 80	4 17	47 49	189·5	0·45	1	6·5 7·0	·131	W.B.
Σ 535	4 18	78 51	327·2	1·60	2	6·7 8·2	·030	W.B.
			329·2	1·38	1	...	·096	H.F.
Σ 553	4 25	39 9	132·0	3·06	1	8·0 8·5	·164	W.B.
Σ 567	4 31	70 43	318·2	1·99	2	8·5 9·0	·036	W.B.
			322·2	1·93	1	...	·096	H.F.
OΣ 86	4 31	70 27	67·8	0·49	1	7·5 7·5	·036	L.
Σ 572	4 32	63 15	201·4	3·80	4	6·5 6·5	·037	W.B.
			201·8	3·56	2	...	·069	H.F.
β 1238... ...	4 55	63 36	12·4	1·41	2	8·1 11·5	·166	L.
Hu. 445 ...	4 56	69 19	290·4	0·47	1	8·5 8·8	·208	L.
Hu. 446 ...	5 1	67 24	180·6	0·83	1	9·2 9·8	·208	L.
Σ 645 A. & $\frac{\text{B.C.}}{2}$	5 3	62 6	25·6	11·81	2	6·2 8·2	·175	L.
β 1047 B.C. ...			54·5	0·49	1	8·2 8·8	·208	L.
OΣ 103 ...	5 12	56 44	57·6	4·22	1	5·2 11·0	·206	L.
β 886 C.D. ...	5 16	56 18	247·5	0·92	1	9·2 10·0	·219	L.
Σ 687 A.B. ...			68·2	17·27	1	8·2 9·0	·219	L.
β 888	5 18	52 42	170·3	8·60	1	6·0 12·0	·219	L.
Σ 715 A.B. ...	5 23	48 48	200·1	0·63	1	8·2 8·9	·219	L.
			51·0	19·45	1	8·2 11·5	·219	L.
Σ 719 A.C. ...	5 24	60 32	351·4	15·01	1	7·0 8·9	·118	W.B.
			349·5	15·14	1	...	·183	H.F.
A.B. ...			328·9	0·82	1	7·0 9·5	·183	H.F.
Σ 749	5 31	63 8	168·9	0·79	2	7·0 7·1	·036	W.B.
Σ 778	5 38	59 7	184·0	3·09	1	7·7 9·0	·203	W.B.
Σ 821	5 52	60 22	0·3	2·29	1	8·0 9·8	·205	W.B.
Σ 867	6 6	72 34	154·3	2·13	1	7·0 8·6	·203	L.
Σ 881	6 13	30 35	103·2	0·87	1	6·4 7·9	·274	L.
Σ 888 A.C. ...	6 14	61 32	251·9	3·04	2	7·5 9·2	·076	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1903.	Obs.
	h m	° ′	°	″				
Σ 899	6 17	72 23	21·5	2·18	2	7·0 8·0	·036	W.B.
OΣ 149 ...	6 30	62 38	260·2	1·47	1	6·5 9·0	·219	L.
Σ 936	6 31	31 49	273·3	1·29	1	7·0 8·7	·274	L.
Σ 942	6 32	66 16	244·8	3·87	2	9·0 9·2	·289	W.B.
Σ 945	6 33	48 56	272·8	0·84	1	7·1 8·0	·274	L.
Σ 946	6 36	30 24	126·8	3·96	1	7·1 9·0	·274	L.
Σ 948 A.B. ...	6 37	30 28	116·0	1·41	1	5·2 6·1	·274	L.
A.C. ...			305·8	8·23	1	5·2 7·4	·274	L.
A.G.C. 1 Sirius	6 41	106 34	112·9	5·82	1	−1·4 10·0	·186	L.
Σ 964	6 43	46 8	193·2	1·83	1	8·3 9·0	·205	W.B.
Σ 991	6 51	64 50	168·9	3·74	1	8·0 9·0	·219	L.
Σ 1001 A.B. ...	6 55	35 41	64·6	9·05	1	7·1 8·7	·274	L.
B.C. ...			357·0	1·45	1	8·7 9·0	274	L.
Σ 1008... ...	6 56	63 15	272·6	2·53	2	8·0 10·0	·300	W.B.
Σ 1024... ...	7 3	51 41	316·0	1·28	2	8·3 8·8	·294	W.B.
Σ 1037... ...	7 7	62 36	295·6	0·75	2	7·1 7·1	·162	W.B.
			303·0	0 71	1	...	·183	H.F.
Σ 1070... ...	7 15	55 46	323·5	2·04	1	8 2 9·2	·279	W.B.
Σ 1074 A.B. ...	7 15	89 25	146·0	0·43	1	7·8 8·2	·192	L.
A C. ...			104·2	12·12	1	7·8 13·0	·192	L.
A.D. ...			12·6	16·05	1	7·8 13·0	·192	L.
Ho. 243 ...	7 16	60 33	168·9	2·81	1	9·3 9·5	·219	L.
Σ 1079 A.B. ...	7 18	51 57	331·7	5·87	1	8·5 10·0	·290	W.B.
C.D. ...			63·1	2·05	1	9·5 9·5	·290	W.B.
Berlin (B.) 2941	7 20	67 43	174·3	2·06	1	8·7 10·3	·186	L.
Σ 1093... ...	7 23	39 49	147·0	0·54	3	8·2 8·2	·296	W.B.
Σ 1110... ...	7 28	57 53	223·9	5·67	2	2·7 3·7	·161	W.B.
Procyon ...	7 34	84 31	355·2	4·93	2	1·0 9·0	·294	W.B.
Σ 1126... ...	7 35	84 32	149·9	1·12	1	7·2 7·5	·183	H.F.
			146·9	1·01	1	...	·192	W.B.
			144·8	1·00	1	...	·219	L.
Ho. 247 ...	7 40	68 42	107·4	0·39	1	7·5 8·0	·263	W.B.
Σ 1147... ...	7 44	65 13	164·7	2·42	1	9·0 9·0	·279	W.B.
Σ 1165... ...	7 54	35 7	274·5	0·58	1	8·0 10·3	·290	W.B.
Σ 1172... ...	7 57	34 59	244·0	1·68	1	7·6 9·4	·290	W.B.
β 581 $\frac{\text{A.B.}}{2}$ & C.	7 59	77 26	194·4	4·69	1	8·3 11·0	·312	L.
Σ 1187... ...	8 3	57 29	44·1	2·29	2	7·1 8·0	·199	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1903.	Obs.
	h m	° ′	°	″				
Σ 1187... ...	8 3	57 29	46·1	2·17	2	7·1 8·0	·257	L.
Σ 1196 A.B. ...	8 6	72 3	351·5	1·11	3	5·0 5·7	·252	W.B.
			355·0	0·88	1	...	·288	H.F.
A.C. ...			110·2	5·43	3	5·0 6·5	·252	W.B.
B.C. ...			122·6	6·08	2	5·7 6·5	·228	W.B.
$\frac{A.B.}{2}$ & C.			118·3	5·66	1	5·0 6·5	·301	W.B.
Σ 1197... ...	8 7	60 8	105·0	1·71	1	8·2 9·0	·295	L.
Σ 1202... ...	8 8	78 51	315·3	2·53	1	7·7 9·8	·192	W.B.
Ho. 524 ...	8 10	71 0	340·1	3·80	1	8·0 11·0	·312	L.
Σ 1211... ...	8 12	50 42	126·2	1·06	1	8·7 9·2	·295	L.
Ho. 525 ...	8 17	69 40	147·5	0·47	1	8·5 8·5	·241	W.B.
			161·2	0·61	2	...	·308	L.
Σ 1225... ...	8 22	38 29	192·8	3·75	1	8·5 8·5	·298	W.B.
Σ 1235... ...	8 26	32 44	85·1	1·24	1	8·0 10·0	·337	W.B.
Σ 1242... ...	8 29	42 32	175·1	2·60	1	8·6 9·3	·295	L.
Σ 1244... ...	8 31	47 51	1·0	3·68	1	8·2 9·8	·295	L.
Berlin (B.) 3449	8 31	66 24	6·1	1·74	1	9·2 10·2	·304	L.
β 585	8 35	69 10	103·0	0·47	2	7·7 9·0	·308	L.
Ho. 354 ...	8 37	63 35	182·8	1·00	2	8·2 8·8	·247	L.
β 209	8 37	50 50	181·9	1·51	1	8·2 8·7	·295	L.
Ho. 251 ...	8 40	64 19	154·5	4·01	1	8·5 12·2	·304	L.
Σ 1273 A.B. ...	8 41	83 13	147·1	0·23	2	3·8 6·0	·245	L.
			144·2	0·25	2	...	·294	W.B.
$\frac{A.B.}{2}$ & C.			236·0	3·40	3	3·8 7·7	·260	W.B.
			231·7	3·58	3	...	·264	L.
Σ 1279... ...	8 43	50 3	268·1	1·38	1	8·3 8·3	·295	L.
Σ 1275... ...	8 44	32 6	14·4	1·97	1	8·0 8·0	·312	L.
Ho. 40... ...	8 45	58 13	286·5	0·69	1	9·0 9·3	·312	L.
Berlin (B.) 3559	8 45	66 30	74·1	1·98	1	9·0 9·1	·304	L.
Σ 1289... ...	8 48	46 2	4·4	3·90	1	7·0 8·5	·301	W.B.
Σ 3121... ...	9 12	61 0	26·9	0·49	3	7·5 7·8	·273	W.B.
			18·6	0·75	1	...	·304	L.
Ho. 43... ...	9 13	68 47	283·4	0·46	1	8·0 8·5	·241	W.B.
OΣ 201 ...	9 18	61 39	226·0	1·49	2	7·5 9·0	·232	W.B.
			218·1	1·64	1	...	·312	L.
Σ 1348... ...	9 19	83 13	317·8	1·78	1	7·5 7·6	·192	W.B.
Σ 1374... ...	9 35	50 35	287·9	3·46	1	7·0 8·3	·342	L.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1903.	Obs.
	h m	° ′	°	″				
Σ 1374... ...	9 35	50 35	288·5	2·94	1	7·0 8·3	·383	W.B.
Σ 1389... ...	9 47	62 32	311·8	2·20	2	8·0 9·0	·291	W.B.
W.B. (2) X 128–9	10 9	71 38	9·0	1·34	2	8·0 8·5	·252	W.B.
			6·7	1·57	1	...	·312	L.
OΣ 215 ...	10 11	71 46	210·5	0·79	3	7·0 7·2	·261	W.B.
			206·6	0·83	1	...	·288	H.F.
Σ 1424... ...	10 14	69 39	116·9	3·54	1	2·0 3·5	·301	W.B.
			117·9	3·81	1	...	·312	L.
OΣ 217 ...	10 21	72 16	146·7	0·85	2	7·3 7·8	·271	W.B.
Σ 1426 A.B. ...	10 15	83 4	286·3	0·71	1	7·5 8·0	·288	H.F.
Σ 1429... ...	10 20	64 53	256·0	1·06	3	8·3 8·3	·277	W.B.
Σ 1457... ...	10 34	83 46	317·7	1·15	1	7·6 8·5	·288	H.F.
OΣ 228 ...	10 42	66 54	193·2	0·45	1	7·2 8·1	·263	W.B.
OΣ 229 ...	10 42	48 21	320·4	0·78	2	6·7 7·1	·315	W.B.
			315·0	0·86	1	...	·312	L.
Ho. 48... ...	10 59	66 18	5·8	1·63	1	8·3 11·0	·263	W.B.
			8·8	1·58	2	...	·389	L.
Σ 1504... ...	10 59	85 49	291·1	0·96	1	7·5 7·6	·288	H.F.
Ho 378 ...	10 59	51 2	43·6	0·25	1	8·0 8·1	·397	L.
Σ 1517... ...	11 8	69 19	265·0	0·52	4	7·3 7·3	·268	W.B.
			267·3	0·43	2	...	·389	L.
Lal. 21846 ...	11 24	58 59	7·6	1·08	2	7·0 11·5	·389	L.
OΣ 234 ...	11 25	48 10	136·0	0·28	1	7·0 7·5	·340	W.B.
			146·8	0·32	2	...	·389	L.
Ho. 51... ...	11 27	81 34	181·9	2·89	2	7·0 11·5	·389	L.
Σ 1554... ...	11 31	76 36	256·3	0·93	1	8·8 8·8	·337	W.B.
Σ 1555 A.B. ...	11 31	61 40	349·5	0·31	2	6·4 6·8	·315	W.B.
			349·1	0·36	2	...	·389	L.
OΣ 237 ...	11 34	48 18	260·8	1·20	2	7·5 9·0	·389	L.
Σ 1586... ...	11 52	49 6	259·4	1·62	1	8·3 11·0	·380	L.
Σ 1606... ...	12 6	49 33	329·0	1·17	2	6·3 7·0	·389	L.
			334·2	1·58	1	...	·460	H.F.
Ho. 536 ...	12 16	54 26	102·8	3·63	1	8·5 9·7	·397	L.
Σ 1639... ...	12 19	63 52	3·9	0·45	1	6·7 7·9	·359	L.
			356·0	0·35	2	...	·428	W.B.
Ho. 53... ...	12 19	75 30	295·5	2·34	1	8·3 11·0	·337	W.B.
Σ 1643... ...	12 22	62 25	40·6	2·34	2	8·7 9·2	·300	W.B.
			38·7	1·99	1	...	·359	L.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights	Mags.	Epoch 1903.	Obs.
	h m	° ′	°	″				
Σ 1647... ...	12 25	79 44	45·3	1·55	2	7·5 7·8	·300	W.B.
B.D + 2°·2550	12 26	87 20	289·0	1·44	1	8·5 8·8	·337	W.B.
B.D + 23°·2471	12 28	66 26	136·0	1·15	1	8·8 9·0	·359	L.
Hu. 571 ...	12 28	69 27	76·0	0·29	1	8·8 8·8	·359	L.
Σ 1658... ...	12 30	82 0	0·6	2·38	1	8·5 10·0	·337	W.B.
Ho. 537 ...	12 30	55 17	185·1	1·03	1	8·0 10·0	·397	L.
Σ 1661... ...	12 31	78 3	239·6	2·56	2	8·5 8·5	·300	W.B.
Σ 1663... ...	12 32	68 15	99·9	0·62	2	7·8 8·7	·300	W.B.
			100·0	0·75	1	...	·359	L.
Ho. 256 ...	12 39	53 41	108·7	0·70	1	7·0 9·0	·397	L.
Σ 1687... ...	12 48	68 13	81·1	1·25	1	5·0 7·8	·422	W.B.
			79·2	1·58	1	...	·460	H.F.
Ho. 538 ...	12 52	68 27	121·0	2·55	1	8·7 12·0	·422	W.B.
Σ 1711... ...	12 58	75 59	347·0	0·82	3	8·5 9·0	·404	W.B.
Ho. 257 ...	13 1	63 34	154·5	2·24	3	8·8 8·9	·404	W.B.
✱ near OΣ 260	13 2	62 31	194·7	0·51	2	9·0 9·5	·454	W.B.
OΣ 260... ...	13 3	62 31	119·7	0·50	2	7·9 8·3	·418	W.B.
Hu. 572 ...	13 4	68 1	352·0	0·43	3	8·0 9·0	·442	W.B.
Σ 1728... ...	13 5	71 57	196·5	0·36	2	6·0 6·0	·395	W.B.
			199·2	0·47	1	...	·460	H.F.
OΣ 261... ...	13 7	57 23	344·9	1·60	2	6·9 7·4	·449	W.B.
			347·2	1·50	1	...	·460	H.F.
β 800	13 12	72 27	109·6	3·04	2	7·1 10·2	·418	W.B.
Σ 1734... ...	13 16	86 32	190·7	1·28	2	7·2 7·9	·373	W.B.
Σ 1742... ...	13 19	88 5	351·7	1·17	2	7·4 7·9	·373	W.B.
Ho. 260 ...	13 19	60 15	326·3	0·86	1	8·3 8·5	·359	L.
			324·1	0·90	2	...	·454	W.B.
Berlin (B.) 4789	13 22	69 1	302·6	1·69	2	9·1 9·5	·419	W.B.
β 113	13 24	78 0	213·1	1·19	1	8·5 10·2	·460	H.F.
Σ 1757... ...	13 29	89 48	79·9	2·69	2	7·8 8·9	·373	W.B.
Σ 1768... ...	13 33	53 13	133·4	1·11	2	5·7 7·6	·418	W.B.
β 801	13 42	78 40	326·5	2·63	1	8·1 10·9	·460	H.F.
Σ 1785... ...	13 45	62 31	293·4	1·58	2	7·2 7·5	·423	W.B.
Σ 1808... ...	14 6	62 56	76·6	2·80	2	8·0 9·0	·373	W.B.
OΣ 278... ...	14 8	45 1	94·5	0·25	3	7·5 7·5	·460	W.B.
Ho. 57 B.C. ...	14 9	47 7	319·2	0·77	2	8·0 13·0	·389	L.
Σ 1819... ...	14 10	86 24	355·5	1·31	1	7·9 8·0	·367	W.B.
Ho. 545 ...	14 30	59 44	317·2	0·65	3	8·3 8·3	·465	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.		Epoch 1903.	Obs.
	h m	° ′	°	″					
Σ 1865... ...	14 36	75 51	145·7	0·36	3	3·5	3·9	·466	W.B.
Σ 1867... ...	14 36	58 17	13·8	1·26	4	7·7	8·2	·453	W.B.
			17·6	1·23	1	...		·460	H.F.
Σ 1877... ...	14 41	62 30	326·4	2·86	2	3·0	6·3	·373	W.B.
OΣ 285... ...	14 42	47 11	125·1	0·33	3	7·1	7·6	·494	W.B.
Ho. 263 ...	14 43	65 30	177·2	0·97	1	7·0	10·0	·509	W.B.
Σ 1883... ...	14 44	83 37	243·3	0·45	3	7·0	7·0	·471	W.B.
Σ 1888... ...	14 47	70 29	180·4	2·70	2	4·7	6·6	·373	W.B.
OΣ 287... ...	14 48	44 40	320·2	0·72	3	7·5	7·6	·494	W.B.
β 31 A.B. ...	14 48	70 51	193·5	1·57	3	8·4	9·7	·500	W.B.
Ho. 389 ...	14 48	69 18	95·7	1·60	2	7·0	9·3	·462	W.B.
OΣ 288... ...	14 49	73 53	188·7	1·78	2	6·4	7·1	·373	W.B.
Σ 1908... ...	15 1	55 9	147·5	1·72	2	8·2	9·2	·496	W.B.
Ho. 60... ...	15 10	54 44	36·5	0·32	2	7·5	7·6	·548	W.B.
			29·9	0·49	1	...		·545	L.
* following Ho. 60 ...	15 10	54 44	59·7	0·11	1	...		·490	W.B.
Σ 1932... ...	15 14	62 48	156·9	0·57	3	5·6	6·1	·434	W.B.
Ho. 264 ...	15 17	73 8	323·3	1·16	2	8·0	12·0	·538	L.
Hu. 146 ...	15 17	68 35	171·9	0·42	2	8·7	9·0	·538	L.
Ho. 62... ...	15 17	54 40	285·0	1·29	2	8·2	8·3	·492	W.B.
Σ 1937... ...	15 19	59 21	16·7	0·93	3	5·2	5·7	·466	W.B.
Σ 1938... ...	15 21	52 18	67·2	1·20	2	6·7	7·3	·459	W.B.
Σ 1940... ...	15 21	71 30	324·9	1·13	2	8·2	8·7	·548	L.
Aitken 82 ...	15 23	65 44	320·0	0·79	2	8·5	9·3	·519	L.
Hu. 577 ...	15 28	69 55	24·7	0·38	2	8·0	8·0	·538	L.
Σ 1954... ...	15 30	79 7	183·9	3·74	1	3·0	4·0	·367	W.B.
			189·2	4·02	1	...		·460	H.F.
			189·3	3·94	1	...		·468	L.
OΣ 298... ...	15 33	49 52	187·4	1·34	2	7·0	7·3	·486	W.B.
Hu. 580 ...	15 37	70 0	71·0	0·27	3	5·0	5·0	·466	W.B.
β 619	15 39	76 2	7·2	0·47	2	6·5	7·0	·519	L.
			2·5	0·45	2	...		·496	W.B.
Σ 1967... ...	15 39	63 23	122·4	0·48	2	4·0	7·0	·496	W.B.
OΣ 303... ...	15 56	76 27	141·9	0·77	3	7·4	7·9	·500	W.B.
Σ 2006 A B. ...	16 0	30 47	202·2	1·76	1	7·5	9·2	·586	L.
Σ 2011... ...	16 4	60 44	72·2	2·21	1	7·2	9·8	·608	W.B.
* near Ho. 551	16 9	63 5	142·9	2·61	2	7·0	11·5	·560	L.
Σ 2021... ...	16 9	76 12	335·5	3·86	1	6·7	6·9	·378	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1903.	Obs.
	h m	° ′	°	″				
Σ 2021	16 9	76 12	334·9	3·89	1	6·7 6·9	·468	L.
Σ 2027... ...	16 10	85 29	79·8	1·68	1	8·2 8·2	·610	H.F.
Σ 2026... ...	16 11	82 23	205·3	0·77	2	8·6 9·1	·560	L.
Σ 2035... ...	16 14	63 54	35·3	2·46	1	8·7 10·9	·608	W.B.
Hu. 481 ...	16 17	...	229·5	0·50	4	...	·511	W.B.
			227·3	0·35	1	...	·525	L.
Hu. 482 ...	16 18	...	23·4	0·52	2	...	·538	L.
Hu. 483 ...	16 23	...	205·6	0·26	2	...	·560	L.
Σ 2052... ...	16 25	71 23	90·6	1·60	1	7·5 7·5	·378	W.B.
			89·9	1·57	1	...	·468	L.
Σ 2055 λ Ophiuchi	16 26	87 48	58·6	1·30	2	4·0 6·1	·463	W.B.
OΣ 313 ...	16 29	49 40	337·0	0·75	1	7·2 7·8	·660	L.
Σ 2062... ...	16 30	81 7	116·8	2·50	1	8·3 10·0	·610	H.F.
Σ 2067... ...	16 30	50 52	300·1	2·59	1	8·5 10·0	·586	L.
Hu. 486 ...	16 35	67 4	144·3	1·16	3	9·0 10·0	·540	L.
Σ 2084... ...	16 38	58 13	190·2	1·36	3	3·0 6·5	·514	W.B.
			190·6	0·98	1	...	·550	L.
Σ 2089... ...	16 39	64 42	61·6	2·52	1	8·0 11·5	·525	L.
Σ 2091... ...	16 39	48 37	300·5	0·84	1	7·5 8·0	·659	L.
Σ 2094... ...	16 40	66 18	73·3	1·51	1	7·3 7·6	·525	L.
Do. 15	16 41	46 20	307·6	0·68	1	8·2 8·6	·659	L.
β 43	16 43	87 5	245·6	0·90	1	8·2 8·3	·556	H.F.
Hu. 666 ...	16 43	66 49	200·2	0·62	1	8·7 12·5	·550	L.*
OΣ 315... ...	16 46	88 37	158·5	0·70	1	6·2 8·1	·556	H.F.
Σ 2107... ...	16 48	61 10	344·7	0·40	3	6·5 8·0	·522	W.B.
Σ 3107... ...	16 54	85 53	95·1	1·58	1	8·5 8·5	·468	L.
Σ 2117... ...	16 56	38 3	102·7	1·57	1	8·4 10·6	·586	L.
Σ 2114... ...	16 57	81 24	161·7	1·19	2	6·2 7·4	·519	L.
			163·5	0·97	1	...	·556	H.F.
Ho. 411 ...	16 59	66 9	268·9	1·39	1	8·3 12·0	·468	L.
Σ 2121... ...	17 0	47 57	147·0	2·76	1	8·0 10·0	·586	L.
Ho. 555 ...	17 1	56 38	186·6	1·67	2	9·5 9·5	·558	L.
Σ 2133... ...	17 6	40 7	199·6	3·39	1	9·0 10·5	·586	L.
Σ 2140 α Herculis	17 10	75 30	114·8	4·77	1	3·0 6·1	·468	L.
			111·4	4·81	2	...	·526	W.B.
Σ 2145 A.C. ...	17 13	63 18	181·0	13·40	2	8·0 9·5	·498	L.
			179·8	13·54	1	...	·531	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1903.	Obs.
	h m	° ′	°	″				
Σ 2145 A.B. ...	17 13	63 18	52·1	0·43	2	8·3 8·9	·498	L.
			44·1	0·38	2	...	·542	W.B.
β 628	17 15	57 14	347·9	0·48	1	9·0 9·5	·568	L.
β 629	17 15	57 50	338·9	0·94	1	8·2 9·0	·685	L.
Ho. 415 ...	17 19	64 9	328·1	1·48	2	8·0 8·7	·492	W.B.
Ho. 414 ...	17 19	63 49	87·5	0·69	2	8·4 8·8	·515	W.B.
			84·1	0·55	1	...	·525	L.
β 46	17 19	76 31	198·3	1·97	2	8·0 11·0	·526	W.B.
Hu. 671 ...	17 20	68 0	266·0	0·43	3	8·4 9·0	·566	W.B.
Σ 2163... ...	17 20	47 47	92·7	1·53	1	9·2 9·2	·660	L.
β 1250... ...	17 21	59 9	72·3	1·91	3	9·4 9·5	·537	W.B.
			70·6	2·40	1	...	·545	L.
Σ 2173... ...	17 25	90 59	325·2	0·82	1	5·8 6·1	·537	H.F.
β 631	17 35	90 36	54·9	0·46	1	7·5 7·6	·537	H.F.
Σ 2196... ...	17 37	68 48	262·3	3·66	2	9·2 11·2	·611	W.B.
β 1251... ...	17 38	74 0	61·6	1·27	3	6·0 11·5	·586	W.B.
Σ 2203... ...	17 38	48 18	317·0	0·65	1	7·5 7·8	·660	L.
Σ 2210... ...	17 40	40 57	122·2	3·25	1	8·5 10·0	·660	L.
Ho. 560 ...	17 40	56 0	94·7	0·52	3	8·0 8·0	·586	W.B.
Σ 2205... ...	17 40	72 14	306·9	2·06	2	8·3 8·7	·483	W.B.
Σ 2214 B.C. ...	17 40	46 13	149·3	1·56	1	8·8 10·3	·660	L.
A.B. ...			211·3	19·90	1	8·5 8·8	·660	L.
Σ 2215... ...	17 41	72 15	288·4	0·91	2	5·9 7·9	·483	W.B.
Ho. 70... ...	17 42	59 26	104·6	0·47	3	8·1 8·1	·586	W.B.
A.C. 7	17 43	62 13	68·0	1·60	2	9·5 11·0	·573	W.B.
Σ 2236... ...	17 47	54 32	94·2	3·29	1	7·8 9·8	·690	H.F.
			96·1	2·88	1	...	·685	L.
OΣ 338... ...	17 47	74 39	19·3	0·65	3	6·6 6·9	·483	W.B.
Σ 2238... ...	17 47	52 17	285·6	2·24	1	9·2 9·7	·690	H.F.
			283·7	2·88	1	...	·685	L.
Aitken 234 ...	17 49	64 23	28·6	0·35	1	8·8 9·1	·674	W.B.
A.C. 9	17 50	60 10	59·3	1·16	3	8·3 8·7	·518	W.B.
Ho. 73... ...	17 54	54 18	39·8	2·10	1	9·0 9·0	·679	L.
Ho. 74... ...	17 55	56 30	30·7	2·99	1	8·7 12·7	·660	L.
Σ 2262... ...	17 58	98 11	258·6	1·56	2	5·0 5·7	·547	H.F.
Σ 2267... ...	17 58	49 49	247·3	1·08	1	8·0 8·0	·452	L.
Σ 2272... ...	18 0	87 28	188·9	1·98	11	4·1 6·1	·528	W.B.
OΣ 341 ...	18 2	68 34	88·4	0·44	1	6·4 7·7	·537	H.F.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1903.	Obs.
	h m	° ′	°	″				
OΣ 341... ...	18 2	68 34	87·6	0·40	2	6·4 7·7	·573	W.B.
Σ 2282... ...	18 3	49 39	271·5	2·50	1	7·2 8·2	·454	L.
Σ 2281... ...	18 5	86 1	237·7	0·34	2	6·7 7·2	·545	W.B.
			232·0	0·53	1	...	·557	H.F.
Σ 2289... ...	18 6	73 32	233·5	1·29	2	6·0 7·1	·485	W.B.
Σ 2298... ...	18 9	48 37	180·6	2·30	1	8·5 9·7	·690	H.F.
Σ 2296... ...	18 10	93 23	7·0	3·21	1	6·7 10·3	·613	W.B.
B.D. + 21°·3386	18 16	68 43	190·8	1·43	4	9·0 9·2	·564	W.B.
			190·8	1·47	1	...	·539	H.F.
A.C.			9·5	13·24	2	9·0 12·0	·559	W.B.
Ho. 430 ...	18 17	69 33	193·0	2·44	3	8·5 9·0	·535	W.B.
β 641	18 18	68 32	344·0	1·11	2	7·5 9·0	·526	W.B.
Σ 2320... ...	18 24	65 25	7·4	1·53	2	7·1 9·0	·526	W.B.
Σ 2324... ...	18 26	88 44	323·5	2·29	1	8·2 8·5	·695	L.
Σ 2328... ...	18 26	60 8	72·5	3·64	1	8·0 8·3	·707	H.F.
OΣ 354 ...	18 27	83 17	174·7	0·91	1	7·2 8·0	·695	L.
Σ 2339... ...	18 29	72 21	273·5	2·41	1	7·2 8·0	·695	L.
Σ 2344... ...	18 31	61 21	174·9	1·73	2	8·5 12·0	·801	W.B.
OΣ 357 ...	18 31	78 21	230·8	0·40	3	7·5 7·6	·544	W.B.
OΣ 358 ...	18 31	73 6	12·4	1·90	2	6·8 7·2	·526	W.B.
			12·7	2·05	1	...	·695	L.
Σ 2349... ...	18 33	56 37	204·9	1·28	1	5·5 10·7	·737	L.
Σ 2352... ...	18 33	55 14	284·9	3·27	1	7·3 10·3	·737	L.
Σ 2356... ...	18 34	61 23	54·9	0·97	2	8·0 9·0	·526	W.B.
* with Σ 2356	18 35	61 22	253·4	1·40	1	9·0 9·0	·520	W.B.
Σ 2358... ...	18 35	59 22	221·8	2·68	1	8·8 9·0	·767	H.F.
Σ 2360... ...	18 35	69 9	3·5	2·53	1	7·5 8·7	·767	H.F.
Σ 2362... ...	18 35	54 3	181·3	3·94	1	7·1 8·1	·767	H.F.
Σ 2367 A.B. ...	18 37	59 48	81·8	0·30	1	7·0 7·5	·737	L.
A.C. ...			191·1	14·13	1	7·0 8·2	·737	L.
Σ 2368... ...	18 37	37 45	329·2	1·86	1	7·2 8·4	·821	W.B.
Ho. 437 A.B....	18 37	58 27	299·6	0·36	1	8·3 8·5	·737	L.
C.D....			338·9	3·46	1	11·2 11·7	·737	L.
*	18 37	58 31	163·7	2·97	1	7·5 10·0	·737	L
Σ 2369... ...	18 39	87 29	92·3	0·91	2	7·5 8·0	·584	H.F.
Σ 2375... ...	18 41	84 36	113·8	2·14	2	6·2 6·6	·548	H.F.
			114·6	2·52	1	...	·821	W.B.
Σ 2400 B.C. ...	18 44	73 52	39·8	0·71	1	10·6 11·0	·737	L.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1903.	Obs.
	h m	° ′	°	″				
Σ 2400 A.B. ...	18 44	73 52	179·2	2·60	1	8·1 10·6	·737	L.
A.C. ...			181·5	3·41	1	8·1 11·0	·737	L.
Σ 2402... ...	18 45	79 26	25·7	1·10	2	8·0 8·4	·575	H.F.
			28·5	0·97	2	...	·605	W.B.
Ho. 89... ...	18 50	52 39	168·8	0·43	1	8·0 12·0	·737	L.
β 137	18 51	52 45	133·1	1·35	1	8·3 8·5	·737	L.
Σ 2422... ...	18 53	64 2	89·4	0·78	2	7·6 7·7	·545	W.B.
			95·0	0·74	1	...	·539	H.F.
Σ 2437... ...	18 58	70 58	60·7	0·82	2	7·8 8·0	·603	W.B.
			60·0	0·84	1	...	·539	H.F.
Σ 2448... ...	19 0	54 28	191·0	2·45	1	8·2 8·2	·767	H.F.
Ho. 95... ...	19 2	62 52	221·9	0·42	3	8·0 8·0	·606	W.B.
Σ 2455	19 3	67 59	75·8	3·54	1	7·2 8·3	·539	H.F.
			72·7	3·51	1	...	·591	W.B.
Ho. 444 ...	19 5	63 13	75·8	1·31	3	8·4 10·0	·617	W.B.
β 1204 A.B. ...	19 7	87 33	3·6	0·37	1	7·7 8·5	·557	H.F.
Ho. 101 ...	19 9	59 10	105·8	1·95	1	9·3 10·0	·512	L.
Σ 2488... ...	19 11	70 9	329·0	1·56	2	8·5 9·7	·545	W.B.
OΣ 368 ...	19 12	74 1	216·5	0·85	2	7·3 8·5	·594	W.B.
OΣ 371 ...	19 12	62 43	156·6	0·71	3	6·8 6·9	·599	W.B.
Ho. 576 ...	19 16	83 22	181·3	3·85	1	7·0 10·7	·610	H.F.
Σ 2525... ...	19 23	62 52	311·7	0·56	4	7·4 7·6	·626	W.B.
Σ 2536... ...	19 27	72 26	78·0	1·83	1	8·0 11·0	·627	L.
OΣ 375 ...	19 30	72 6	151·9	0·58	3	7·2 8·4	·617	W.B.
			154·1	0·52	1	...	·627	L.
Σ 2544 A.B. ...	19 32	81 55	210·7	0·94	1	7·8 9·5	·610	H.F.
			206·7	1·01	1	...	·627	L.
β 658	19 40	63 7	285·6	0·52	1	6·5 9·5	·627	L.
Σ 2583... ...	19 44	78 26	114·4	1·21	1	6·0 6·8	·819	H.F.
Σ 2584... ...	19 44	68 5	296·8	2·06	1	8·5 8·5	·525	L.
Σ 2586... ...	19 44	65 16	224·8	3·75	1	7·3 10·2	·525	L.
OΣ 387 ...	19 45	54 58	327·2	0·53	4	7·2 8·2	·697	W.B.
Σ 2585 A.C. ...	19 45	71 6	310·2	8·56	5	5·7 8·8	·617	W.B.
A.G.C. 11 A.B.			154·3	0·21	2	5·7 6·2	·807	W.B.
Ho. 580 ...	19 48	67 48	272·3	0·69	3	8·0 8·1	·579	W.B.
Σ 2596... ...	19 49	74 59	327·7	1·95	1	7·2 8·6	·819	H.F.
Σ 2597... ...	19 50	97 0	89·1	1·40	1	6·9 8·0	·610	H.F.
Σ 2600... ...	19 51	67 46	56·7	3·21	2	8·3 9·7	·545	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.		Epoch 1903.	Obs.
	h m	° ′	°	″					
Σ 2600... ...	19 51	67 46	58·5	3·10	2	8·3	9·7	·541	L.
B.D. + 24°·3798 A.B. ...	19 54	68 8	276·9	1·25	2	9·0	10·4	·541	L.
			277·7	1·50	2	...		·641	W.B.
A.C. 16 ...	19 54	63 1	61·1	0·36	1	7·8	8·2	·512	L.
Ho. 583 ...	19 55	68 10	257·0	1·54	1	9·0	10·7	·630	W.B.
			263·6	2·02	1	...		·512	L.
			279·5	2·00	1	...		·512	L.
			294·4	2·44	1	...		·512	L.
Σ 2605... ...	19 55	57 0	136·9	1·12	1	7·5	8·2	·737	L.
Σ 2607 A.C. ...	19 55	48 0	293·3	3·18	1	7·2	9·2	·512	L.
OΣ 392 A.B. ...			305·4	0·33	1	7·2	9·0	·512	L.
OΣ 395 ...	19 58	65 21	99·8	0·64	3	5·8	6·2	·580	W.B.
Σ 2616... ...	19 58	75 42	254·8	3·47	1	6·8	9·7	·873	W.B.
Σ 2620... ...	19 59	78 30	293·4	1·86	1	8·2	9·3	·868	L.
Σ 2624... ...	20 0	54 15	174·4	1·99	1	7·2	7·8	·912	W.B.
Σ 2626... ...	20 0	59 45	125·8	1·23	1	8·0	8·2	·923	W.B.
β 57	20 1	74 47	122·4	2·12	1	6·7	11·3	·868	L.
Σ 2627... ...	20 2	85 32	30·5	3·91	1	9·0	11·5	·868	L.
OΣ 398 ...	20 4	54 34	76·4	0·98	1	7·3	9·8	·512	L.
Σ 2651... ...	20 9	74 9	109·5	1·40	1	8·0	8·0	·873	W.B.
Σ 2665... ...	20 15	75 57	19·1	3·28	1	6·5	9·2	·873	W.B.
Σ 2666... ...	20 15	49 35	246·5	2·53	1	6·5	8·7	·901	H.F.
Σ 2668... ...	20 17	50 56	288·2	3·30	1	7·0	9·2	·923	W.B.
Ho. 457 A.B. ...	20 21	60 58	61·0	1·96	2	8·1	8·1	·545	W.B.
β 670	20 28	76 24	41·9	0·50	2	8·5	8·9	·701	W.B.
Σ 2695... ...	20 28	64 32	76·4	1·05	2	6·2	8·0	·545	W.B.
β 151 A.B. ...	20 32	75 45	38·9	0·24	4	4·7	6·1	·700	W.B.
			34·3	0·35	1	...		·818	H.F.
			47·5	0·29	1	...		·871	L.
Σ 2702... ...	20 32	55 11	204·8	3·34	1	8·5	8·7	·901	H.F.
Σ 2705... ...	20 34	56 59	264·8	3·04	1	7·1	8·1	·912	W.B.
Σ 2723... ...	20 40	78 3	99·6	1·44	1	6·4	8·2	·873	W.B.
Berlin Zone ...	20 41	65 40	357·2	1·95	2	9·0	9·1	·545	W.B.
OΣ 413 ...	20 44	53 53	64·0	0·59	1	5·0	6·3	·912	L.
Σ 2739... ...	20 55	70 20	254·0	3·05	3	8·3	8·8	·782	W.B.
Σ 2744... ...	20 58	88 52	163·3	1·45	2	6·3	7·0	·667	W.B.
			164·4	1·40	2	...		·816	H.F.
Σ 2746... ...	20 58	51 8	293·2	1·08	2	8·0	8·6	·922	L.

Star's Name		R.A. 1900. h m	N.P.D. 1900. ° ′	Position Angle. °	Distance. ″	No. of Nights.	Mags.		Epoch 1903.	Obs.
Hu. 691	...	21 3	55 30	318·7	0·25	1	8·5	9·0	·742	L.
Σ 2762...	...	21 4	60 12	309·6	3·41	2	6·0	8·0	·775	W.B.
				310·8	3·39	1	...		·745	L.
Σ 2765...	...	21 6	80 51	86·8	2·88	1	7·8	8·0	·737	L.
Σ 2767...	...	21 6	70 27	30·4	2·35	2	7·8	8·2	·821	W.B.
Ho. 152	...	21 8	62 4	321·0	0·43	1	8·6	9·2	·742	L.
OΣ 535 A.B.	...	21 10	80 24	20·4	0·26	4	4·1	4·1	·692	W.B.
				23·2	0·31	4	...		·816	L.
				21·2	0·35	2	...		·842	H.F.
OΣ 430	...	21 7	66 15	203·1	1·47	1	7·8	9·8	·742	L.
Σ 2785...	...	21 14	50 40	236·8	3·23	1	8·1	10·0	·912	L.
OΣ 437	...	21 17	57 58	43·2	1·78	1	6·5	7·2	·780	W.B.
Σ 2797...	...	21 22	76 45	217·1	3·16	2	6·7	8·2	·827	W.B.
Σ 2799...	...	21 24	79 21	297·7	1·43	2	6·6	6·6	·614	W.B.
Σ 2802...	...	21 28	56 38	188·8	3·40	1	8·0	8·0	·912	L.
Σ 2804 ..	...	21 28	69 44	335·6	2·74	2	7·3	8·0	·562	W.B.
β 167 ...	...	21 32	60 24	95·4	1·90	1	7·0	12·0	·742	L.
OΣ 445	...	21 35	69 44	293·7	0·72	1	8·0	8·5	·742	L.
OΣ 448	...	21 37	61 7	236·5	2·10	1	7·7	8·7	·742	L.
Σ 2822 A.B.	...	21 40	61 42	121·0	2·17	2	4·0	5·0	·655	W.B.
β 989 A.B.	...	21 40	64 49	124·8	0·26	4	3·9	4·4	·816	L.
				121·2	0·16	3	...		·829	W.B.
Σ 2824 $\frac{\text{A.B.}}{2}$ & C.		...	...	297·4	12·62	2	3·9	10·8	·845	W.B.
Ho. 166	...	21 40	62 37	82·5	0·39	3	7·5	7·5	·791	L.
Berlin (B.) 8379		21 41	68 31	359·7	1·97	2	9·2	9·5	·562	W.B.
Ho. 608	...	21 42	63 10	126·5	0·55	2	8·2	9·7	·741	L.
Ho. 171	...	21 48	62 40	175·8	0·52	4	8·2	8·2	·664	W.B.
Ho. 609	...	21 51	60 45	354·6	3·47	1	9·5	9·8	·868	L.
Σ 2849...	...	21 53	70 15	257·2	1·14	1	8·2	10·7	·912	L.
Σ 2850...	...	21 55	66 32	257·7	2·87	1	7·2	11·2	·868	L.
Ho. 610	...	21 57	63 38	242·4	0·82	2	9·0	9·2	·803	L.
Σ 2854...	...	21 59	76 51	84·5	2·64	2	7·7	8·0	·789	W.B.
Σ 2859...	...	22 1	69 55	339·3	3·56	1	9·0	9·8	·868	L.
Σ 2868...	...	22 5	67 56	357·9	1·01	2	8·3	8·8	·789	W.B.
Berlin (B.) 8568		22 10	68 33	21·1	2·47	2	8·8	9·8	·584	W.B.
Σ 2881...	...	22 10	60 55	97·9	1·51	2	7·7	8·2	·789	W.B.
Σ 2882...	...	22 10	52 45	327·8	2·63	1	9·2	9·2	·912	L.
Σ 2889...	...	22 12	64 14	189·5	2·02	2	8·2	10·8	·946	W.B

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.		Epoch 1903.	Obs.
	h m	° ′	°	″					
Σ 2900... ...	22 19	69 39	184·1	1·68	1	6·0	9·2	·742	L.
Ho. 183 ...	22 20	67 56	219·3	2·36	1	8·2	11·6	·742	L.
Σ 2905... ...	22 22	75 22	283·8	3·12	1	8·5	8·5	·920	H.F.
Σ 2906... ...	22 22	53 4	3·8	3·83	1	7·0	10·6	·912	L.
Σ 2929... ...	22 34	79 59	1·2	1·36	1	9·0	9·5	·920	H.F.
Ho. 296 ...	22 36	75 59	61·8	0·46	2	5·5	5·5	·807	W.B.
Σ 2934... ...	22 37	69 5	150·8	0·83	1	8·2	9·2	·873	W.B.
Σ 2958... ...	22 52	78 41	5·5	3·67	1	7·2	9·5	·969	W.B.
Σ 2968... ...	22 56	59 27	92·6	3·49	1	7·0	9·5	·912	L.
Σ 2969... ...	22 56	63 46	31·1	3·76	1	8·0	9·9	·912	L.
Berlin (B.) 8840	22 59	67 23	231·3	1·61	2	9·0	9·5	·857	W.B.
Σ 2974... ...	23 0	57 10	162·1	2·44	1	8·0	8·0	·912	L.
Σ 2979... ...	23 3	50 44	225·6	3·19	1	8·0	10·0	·958	H.F.
Σ 2989... ...	23 8	70 33	144·9	1·72	1	8·5	9·9	·969	W.B.
Σ 2990... ...	23 8	68 28	63·6	2·18	2	8·5	8·5	·946	W.B.
Σ 3000... ...	23 14	65 20	53·4	3·55	2	8·7	8·8	·983	W.B.
Σ 3012... ...	23 23	73 55	193·6	2·92	1	8·7	8·8	·969	W.B.
			193·9	2·62	1	...		·997	H.F.
Σ 3013... ...	23 23	73 55	277·7	3·15	1	7·8	9·3	·969	W.B.
			278·2	2·98	1	...		·997	H.F.
Σ 3015... ...	23 23	56 59	190·8	3·07	1	8·7	8·8	·997	H.F.
Σ 3020... ...	23 26	71 46	108·0	1·82	1	7·7	9·7	·969	W.B.
Σ 3023... ...	23 27	73 9	282·3	2·05	1	7·0	9·7	·969	W.B.
Σ 3026... ...	23 31	61 39	277·8	3·56	1	8·8	9·3	·969	W.B.
Σ 3041... ...	23 43	73 29	178·9	3·48	2	8·1	8·1	·946	W.B.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXVI. DECEMBER 8, 1905. No. 2

W. H. MAW, Esq., PRESIDENT, in the Chair.

Charles Frederick Aspinwall, B.A., Chestergate, Macclesfield ;
Hubert Hayward Champion, Uppingham School, Rutland ;
Lieut. Alfred Henry Laurence Ferris, R.N.R., Duncarrick, Castlerock, Co. Derry, Ireland ; and
Edward MacFarlane, Under-Secretary for Lands and Chief Surveyor for New South Wales, Department of Lands, Sydney, Australia,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Robert Courtenay, B.A. (Dublin), Indian Civil Service (retired), 34 Wilmount Street, Woolwich (proposed by A. M. W. Downing) ;
Chetwode G. G. Crawley, A.B. (T.C.D.), Lieut. R.M. Artillery, R.N. Staff of Science Instructors, H.M.S. Vernon, Portsmouth (proposed by Isaac Molloy) ; and
John Milne Gardiner Shaw, Mem. Inst. Naval Architects, F.R. Met. Soc., c/o John Swire and Sons, 8 Billiter Square, London, E.C. (proposed by E. T. Whittaker).

Sixty-one presents were announced as having been received since the last meeting ; including amongst others :—

Major C. F. Close, Text book of surveying, presented by the author ; W. G. Hooper, Æther and gravitation, presented by

the author; Observations of the total solar eclipse of 1900 and 1901, presented by the U.S. Naval Observatory.

Frank McClean, Photographs of the Spectrum of Nova *Persei*, presented by Mrs. McClean; Photographs of the total eclipse of 1905 August 30 taken by the Hamburg Observatory Expedition, presented by Professor R. Schoer; Further charts of the Astrographic Chart of the Heavens, presented by the Royal Observatory, Greenwich; Series of transparencies from the negatives of the total solar eclipse of 1905 August, taken at Sfax, Tunis, presented by the Astronomer Royal; Portrait of Sir W. Huggins (lithograph), drawn and presented by Mr. Washington Green.

Note on the Astronomical Value of Ancient Statements of Solar Eclipses. By Simon Newcomb.

In Mr. Cowell's interesting paper on "Ancient Solar Eclipses," in the October number of the *Monthly Notices*, he mentions my views as to the value of ancient records of these eclipses, but fails to state them with entire exactness. I therefore venture to present a brief statement of them.

1. In order that an ancient total eclipse may be utilised for astronomical purposes, the record must inspire a fair confidence that the eclipse was actually total at a well-defined or determinable place of observation.

2. There is only one ancient total eclipse which seems to satisfy this condition, and this is one in which the record of its interpretation is certainly in error. I refer to the eclipse seen by the army of Xerxes, near Sardis, about B.C. 478.

3. Next in order of confidence comes the eclipse of Agathocles, which there is reason to believe was total somewhere in the Hellespont; but this is vague.

4. In no other case is the fact of the eclipse being total at a definite place distinctly stated. It has been tacitly assumed that when an eclipse is mentioned in the annals of an empire, or by a poet or historian, it was total at the capital where the record was made, or at the place where the poet or historian lived.

5. Confronted with the dilemma :—

Either an historian, poet, or chronicler recorded an eclipse in which the limit of totality was an unknown number of miles distant from the point of record; or

The laws of motion of the Moon were different in former ages from what they are now. I choose the first horn of the dilemma.

6. The researches of Brown show that during the past two centuries the motions of the node and perigee of the Moon have coincided with the results of gravitational theory within a limit

of exactness of $1''$ annually. The presumption seems to me fairly strong that this accord has existed for the last 3000 years.

7. In view of the fact that, with the partial exception already mentioned, no ancient chronicler seems ever to have attributed the slightest importance to the question whether an eclipse of the Sun was or was not total at a given place, results based on the assumption that eclipses were total at the several places of record cannot be entitled to any great weight.

8. The act of rejecting the results of gravitational theory in order to secure the best possible representation of these supposed eclipses is subject to judgments similar to those pronounced by the Congregation of Cardinals against the doctrines of Galileo.

Reply to Professor Newcomb's Note. By P. H. Cowell.

The paragraphs are numbered so as to refer to the corresponding paragraphs of Professor Newcomb's note.

1. I agree with Professor Newcomb, but I would add that *à posteriori* evidence (the agreement of the equations of condition) has some value.

2. In all eclipses used by me, with the single exception of the eclipse of −762, there are words in the record implying at least a near approach to totality.

−1062	fire in the midst of heaven
− 647	day turned into night
−430 and − 309	stars seen
+ 197	light nearly extinguished

In giving first place to the eclipse of Xerxes, Professor Newcomb considers the words of the record only: he does not consider the interval of time and place between the event and the historian, nor the character of the historian for accuracy, as inferred from his other writings.

3. My papers are not concerned with the question as to whether the eclipse, stated at the end of the first century A.D. to have been once upon a time total at the Hellespont, was the same as the eclipse of Agathocles.

4. The assumptions mentioned form a good working hypothesis. Only two eclipses would have been necessary if totality at a given place were certain. The concurrence of four additional eclipses is offered to make up for the uncertainty of the historical data.

5. Professor Newcomb is not confronted with this dilemma. Were it so, I should admit that the second horn must be

avoided at all costs. The choice lies between the first horn, as Professor Newcomb states it; or

An acceleration of the Earth's orbital motion must be accepted which will make the eclipses agree well with the most probable interpretation of the records.

6. I am basing my hypothesis of a secular acceleration for the Sun upon the acceptance, and not upon the rejection, of the theoretical position of the node.

7. There are contemporary records of very few eclipses. Great numbers of partial eclipses must have occurred. I attach great weight to the fact that a very simple assumption makes the six eclipses considered central at specified places. In my view we have heard of those eclipses, because they were striking phenomena worth recording. The lunar eclipses and the transits of *Mercury* are not very searching tests, but so far as they go they confirm the assumption referred to.

8. I have not rejected the results of gravitational theory. I at once acquiesced in the following argument as soon as it was presented to me: *

i. The motion of the node accords with theory now to well within 20″ per century, which is therefore the extreme value to be assigned to the action of unknown causes.

ii. Therefore the position of the node twenty-five centuries ago must be considered known to within 500″.

I presume Professor Newcomb does not expect me to consider such an argument as the following conclusive:—

i. No theoretical reason is known for a change in the Earth's mean motion.

ii. Therefore the Earth's mean motion must be constant.

To expect this would be equivalent to saying that theory must always precede observation.

Finally I would say that the question is one of evidence. There must be a degree of evidence that would be considered sufficient to establish the fact. I have produced a considerable amount of evidence, all pointing one way; and the conclusion seems to me highly probable.

On the Transits of Mercury, 1677–1881. By P. H. Cowell.

In this paper I examine the transits of *Mercury* to determine whether they support or contradict the supposition of a secular acceleration of 4″ in the Earth's orbital motion that I have deduced from ancient solar eclipses.

It is well known that the secular acceleration of the Moon cannot be determined from modern observations on account of the term of long period, on which theory is altogether silent;

* In my first paper on ancient solar eclipses I had overlooked Professor Brown's paper on the secular accelerations in the *Monthly Notices* of 1897.

while observation can only give a very rough approximation to its value.

In like manner the assumption that no unknown long-period terms exist in the motion of the Earth or *Mercury* necessarily underlies the present paper, and hence no secular accelerations could have in the first instance been deduced from a discussion of the transits. I show, however, that with the above suppositions the transits of *Mercury* do indicate a secular acceleration for the Earth, but not for *Mercury*. The amount here deduced is $2''\cdot5$ for the Earth, in fair accordance with the $4''$ deduced from ancient eclipses, considering the short extent of time covered by the transits of *Mercury*. For *Mercury* the secular acceleration obtained is $-0''\cdot5$. If this be treated as accidental, and put equal to zero in the equations of condition, the secular acceleration for the Earth goes up to $3''\cdot2$, in still better accordance with the result from ancient eclipses.

The phenomenon, accounted for to a great extent in this paper by the supposition of a secular acceleration for the Sun, is twice recognised by Professor Newcomb in his discussion of the transits of *Mercury* (*Astron. Papers*, vol. i. p. vi). On p. 450 he finds the corrections required by the tabular times to be closely represented by $+60^{s}\cdot T^{2}$, a quantity far too large to be attributed to tidal retardation of the Earth's rotation. Again, on p. 460 he finds that the phenomena can be numerically explained by supposing a long-period inequality in the Earth's rotation sufficient to account for three tenths of the errors of the Moon. That there is something to explain may therefore be taken on the authority of Professor Newcomb. My present point is that a secular acceleration of the Earth does explain the phenomenon with reasonable accuracy, and that the hypothesis is not an arbitrary one invented *ad hoc*, but an hypothesis to which I had already been led by other evidence.

The material I use consists of the internal contacts only. Professor Newcomb (*Astron. Papers*, vol. i. pp. 457–8) has given equations of conditions resulting from fourteen November transits and six May transits, and has assigned weights to each equation of condition. I accept his weights unaltered. I remove, however, from his equations of condition every unknown quantity but V for the November transits and W for the May transits. To do this I substitute $k = 0$ in his equations, and for N, M, S the values that he has obtained on p. 459.

$$N = -0''\cdot16 + 0''\cdot28T$$
$$M = +0\cdot15$$
$$S = -0\cdot04$$

where T is the time measured in centuries from 1820.

It will be seen in Professor Newcomb's paper that N involves a correction to the node and S to the semi-diameters, and that

consequently relatively to V, W (which involve corrections to the longitudes), N and S change sign between second and third contacts. When, therefore, both second and third contacts are employed the values of V, W are very little affected by possible errors in N, S. Again, M involves a correction to the mass of *Venus*. There is not much uncertainty in this correction, and relatively to V, W its effect, though the same at both second and third contacts, changes sign twice or thrice during the period under discussion. Consequently the values of V, W will be very little affected by assuming a value for M.

The quantity k that I put equal to zero was introduced by Professor Newcomb on the hypothesis that the errors of the Moon might be attributed to irregularities in the rotation of the Earth. His solution $k = +0.295$ means that three tenths of the errors of the Moon appear, on solution of the equations of condition, to be attributable to this cause. The choice, however, obviously lies between $k = 0$ (uniform rotation, the explanation of the Moon's errors to be sought elsewhere), and $k = 1$ (Moon's errors entirely explained by irregularities of rotation). An intermediate value of k merely replaces a single difficulty by two, and Professor Newcomb regards $k = 0$ as more probable than $k = 1$.

With these modifications the equations of condition become

November Transits. Internal Contacts.

Date.	Contact.	Equation.	Weight.
1677	II.	$-0.98V - 5''.72 = 0$	Rej
	III.	$+0.96V - 9.46 = 0$	Rej
1677	II. and III.	$-0.97V + 1.88 = 0$	0.3
1697	III.	$+0.75V + 0.69 = 0$	0.3
1723	II.	$-0.95V + 0.97 = 0$	2.0
1736	II.	$-0.51V + 0.20 = 0$	1.0
	III.	$+0.47V - 0.65 = 0$	1.0
1743	II.	$-0.81V + 0.21 = 0$	1.0
	III.	$+0.84V - 0.18 = 0$	1.5
1769	II.	$-0.90V - 0.43 = 0$	1.0
	III.	$+0.88V - 0.53 = 0$	0.2
1782	II.	$-0.23V + 0.11 = 0$	3.0
	III.	$+0.19V - 1.13 = 0$	3.0
1789	II.	$-0.87V + 0.80 = 0$	2.0
	III.	$+0.90V - 1.07 = 0$	1.0
1802	III.	$+1.00V - 0.63 = 0$	3.0
1822	II.	$-0.46V + 0.26 = 0$	0.5
	III.	$+0.51V + 0.55 = 0$	1.0

Date.	Contact.	Equation.	Weight.
1848	II.	$-0.99V-0''.61=0$	5.0
	III.	$+0.98V+0.70=0$	0.3
1861	II.	$-0.75V+0.26=0$	0.7
	III.	$+0.72V+0.76=0$	5.0
1868	II.	$-0.62V+5.90=0$	0.5
	III.	$+0.66V+1.72=0$	6.0
1881	II.	$-0.96V-4.34=0$	3.0
	III.	$+0.97V+3.40=0$	3.0

May Transits. Internal Contacts.

Date.	Contact.	Equation.	Weight.
1740	II.	$-0.29W-1''.76=0$	Rej
1753	III.	$+0.97W+0.47=0$	3.0
1786	II.	$-0.64W+\left\{\begin{matrix}3.59\\1.19\end{matrix}\right\}=0$	Rej
	III.	$+0.73W+1.60=0$	4.0
1799	II.	$-0.95W+0.00=0$	3.0
	III.	$+0.90W-0.28=0$	4.0
1832	II.	$-0.83W+1.47=0$	6.0
	III.	$+0.89W-1.16=0$	6.0
1845	II.	$-0.84W+1.55=0$	8.0
	III.	$+0.77W-1.76=0$	8.0
1878	II.	$-0.94W+1.24=0$	12.0
	III.	$+0.97W-1.34=0$	8.0

Professor Newcomb, who had no grounds for introducing terms proportional to the square of the time into his solution, obtains

$$V=-0''.90-2''.63T$$
$$W=+0.84+1.84T$$

I find

$$V=+0''.28-3''.61T-3''.30T^2$$
$$W=+1.12+2.36T-2.81T^2$$

T being measured from 1820 in units of a century.

The meanings of V and W are

$$\begin{aligned}V&=1.487\delta\lambda-0.487\delta\pi-1.137\delta e\\&\quad-1.01\delta\lambda'+1.19e'\delta\pi'+1.58\delta e'\\W&=0.716\delta\lambda+0.284\delta\pi+0.896\delta e\\&\quad-0.97\delta\lambda'-1.11e'\delta\pi'-1.62\delta e'\end{aligned}$$

where $\delta\lambda$, $\delta\pi$, δe represent the corrections required by the tabular (Le Verrier's tables) mean longitude perihelion and eccentricity of *Mercury*, and accented letters refer to the Earth.

V, W refer to November and May transits respectively. The signs of the coefficients of $\delta\pi$, δe, $\delta\pi'$, $\delta e'$ are naturally changed at the opposite side of the orbits. If we regard δe, $\delta\pi'$, $\delta e'$ as known, the equations of condition determine the two relative distances of the heliocentric positions of three points, *Mercury*, the perihelion of *Mercury*, and the Earth.

Eliminating $\delta\lambda'$ and $\delta\lambda$ successively from the values of V and W

$$\delta\lambda - 1{\cdot}06\delta\pi - 2{\cdot}79\delta e \qquad + 3{\cdot}16e'\delta\pi' + 4{\cdot}41\delta e' = -1''{\cdot}19 - 8''{\cdot}19\mathrm{T} - 0''{\cdot}50\mathrm{T}^2$$

$$-1{\cdot}07\delta\pi - 2{\cdot}98\delta e + \delta\lambda' + 3{\cdot}48e'\delta\pi' + 4{\cdot}92\delta e' = -2''{\cdot}04 - 8''{\cdot}48\mathrm{T} + 2''{\cdot}53\mathrm{T}^2$$

On the further assumption that the secular term on the right hand of the second equation is to be attributed to $\delta\lambda'$, we have

$$\delta\lambda' = +2''{\cdot}53\mathrm{T}^2$$

with similar assumptions

$$\delta\lambda = -0''{\cdot}50\mathrm{T}^2$$

The first result is a fair confirmation of the result from solar eclipses. The second is probably accidental.

A still better accordance with the eclipse value of the secular acceleration of the Earth is obtained by treating the secular acceleration of *Mercury* as zero in the equations of condition. In this manner we obtain from the November transits, 1677–1881

$$\delta\lambda' = +3''{\cdot}27\mathrm{T}^2$$

from the May transits, 1753–1878

$$\delta\lambda' = +2{\cdot}90\mathrm{T}^2$$

Weighting the two values in the proportion 204^2 to 125^2, or 8 to 3, the squares of the extent of the observations in time, we get

$$\delta\lambda' = +3''{\cdot}17\mathrm{T}^2$$

The terms proportional to T are slightly different from those obtained by Professor Newcomb, and they may be worked up by his methods, and slightly different numerical results in consequence obtained. The numerical changes, however, are small in comparison with the arbitrary assumption that δe, $e'\delta\pi'$, $\delta e'$ contain no terms proportional to the time other than those indicated by theory, thus throwing the whole observed discordance upon

$\delta\pi$. Moreover the numerical changes are small compared with the large "observed *minus* theoretical" value of $\delta\pi$, the longitude of the perihelion of *Mercury*. The motion of *Mercury's* perihelion remains anomalous, and is not shown to be the geometrical effect of ignoring secular variations in the tables.

On the Present State of Lunar Nomenclature.
By S. A. Saunder, M.A.

Some apology is due from me for again occupying the time of the Society with a subject so familiar to all selenographers as the confusion now existing in lunar nomenclature, and the inadequacy of our present system for the growing needs of selenography; but, as some recent remarks of mine* have led the Council of this Society to take a course of action which it is hoped may lead to an authoritative reconsideration of the questions involved, I have thought that a fuller statement of the difficulties might be of interest to those whose work lies in other directions, and might also lead to some useful suggestions from those who, like myself, have found themselves hampered by the want of a recognised language in which to express the results of their labours.

Our present system may be said to date from the publication of Beer and Mädler's map in 1837. In this the principal formations, such as Tycho or Copernicus, have separate names allotted to them; the smaller mountains are designated by affixing a letter to the name of some neighbouring principal formation, as Mösting A, Thebit B. But at once difficulties begin to be felt. These smaller mountains are denoted on the map only by the letters A, B . . ., and it is often far from easy to determine to which of the adjacent names this letter should be attached. Mädler was generally careful to place the letter towards that side of the object which was nearer to the named formation, but even in his map it is sometimes difficult to determine the name, and in other maps the position of the letter is no guide at all. The only safe method is to read through all that has been said in the text of *Der Mond*, or of Neison's *Moon*, under each of these headings until a description is found which applies to the mountain under consideration. This may well occupy half an hour, and sometimes three or four times as long may be spent without any result, for there are some of these lettered formations to which I have been unable to find any allusion in the text. It is frequently hard enough to identify a crater at all in a crowded region, and this further demand constitutes a considerable tax upon one's time.

As an instance of the confusion which may arise from this

* *Memoirs R.A.S.* vol. lvii. pp. 47, 48.

difficulty I may cite the valuable set of measures of 150 standard points published by Dr. Franz in *Breslau Mitteilungen*, vol. i.; No. 65 in that list is called Hippalus A, and no other means are given for identifying it except its position and diameter. Now I have measured the same point—it is No. 124 in my catalogue (*Memoirs R.A.S.* vol. lvii. part i.)—and, as my position differs from Dr. Franz's by less than a second of arc, whilst the diameter of the ring is about 9 seconds, there can be no doubt as to our having measured the same point. I am therefore able to identify the point on a photograph, and thence on the map. But, on referring to the text, I conclude that Mädler wrote of this as Agatharchides A, and not Hippalus A. Mädler's Hippalus A is No. 73 on my list, at a distance of nearly a minute of arc and on the other side of Hippalus. Anyone using Dr. Franz's measures as he intended them to be used, either for making a map or for determining the positions of other points, would probably have applied the measure to a wrong point, and, as it would not be absurdly wrong, he might have done a good deal of work before he found even that there was an error, and then a good deal more might be necessary before the true source was located.

A difficulty of the same character sometimes arises from the inaccuracy of the maps. When a point has been observed on the Moon, or on a photograph, it is often extremely difficult to identify it on the maps. Franz mentions this difficulty with regard to several points on his list, and, amongst others, with regard to No. 115, which he calls Pons *c*. Here, again, I have measured the same point (it is No. 1131 in my catalogue), and have come to the conclusion that it is Mädler's Pons *b*. The same confusion as before is not improbable, and these are not the only cases in which it might arise.

I should be very sorry if my selection of these instances from Dr. Franz's catalogue gave rise to an impression that I was actuated by any spirit of fault-finding. Dr. Franz has done so much towards the foundation of an accurate selenography that it would be impossible to speak of his work otherwise than with the highest admiration and respect; but, this being the case, the fact that I find myself obliged deliberately to differ from him in what ought to be so simple a matter as the right names to be applied to several amongst 150 of the most conspicuous measurable points on the Moon will be more convincing than many pages of argument that there is a real necessity for rendering the recognised names more easily discoverable.

But the difficulties do not stop here. Since Mädler's time many selenographers have considered it desirable to add new names to the list. In Mädler's map there were, according to Neison, 427 principal names: 145 of these were new, the rest being taken from the works of older selenographers. In Neison's map, which was published in 1876, there were 513 names. Of the additions one each was due to Webb, Lecoutourier, and

Schmidt, four to Lee, fifty-eight to Birt, and fourteen to Neison, whilst two names which Mädler had been unable to identify were reinstated from Riccioli and five from Schröter. Neison says that sixty-seven of these were taken from the British Association Catalogue, but I have not been able to ascertain that this catalogue was ever published. In 1864 a Committee of the British Association was appointed for the purpose of mapping the surface of the Moon, and this Committee issued five reports in the years 1865–69; but the only thing they did for nomenclature was to suggest a series of symbols which have never been adopted, and which I certainly should not wish to see put forward again.

The subject did occupy the attention of the Selenographical Society, who suggested the partition of the Moon into regions round each of the named formations, and who issued special catalogues of a few of these regions. Such of these, however, as I have examined seem to be based entirely on Neison's map, and they will not stand a detailed comparison with the photographs.

Schmidt's map—by far the best we possess—was published in 1878, and his description of it contains about sixty new names.

Franz has recently * given new names and letters to fifty-three points, and others have made further additions from time to time.

There is no map or catalogue in existence giving a complete list of the names which have been used by even half a dozen of our greatest selenographers; whilst Elger, in his book on *The Moon*, published in 1895, almost entirely neglects the names added by Schmidt, although his map claims to be founded on Schmidt's and to show clearly every named formation.

Schmidt, whose knowledge of the lunar surface has probably never been equalled, mentions several names as in use by English selenographers, but representing formations he has been unable to identify. Some of these may be found in Neison or Elger, but others cannot, and it would require some searching to discover who the authors were and to what formations the names were applied.

It will be seen that the present nomenclature has grown, and is still growing, without any recognised control, whilst the names given by one of the greatest of selenographers have, in this country certainly, and I believe elsewhere, received no recognition.

It has resulted from this that in many instances different formations have received the same names. Each of the following has been allotted to two: Peters, Carrington, Beer, Argelander, Janssen, Leverrier, Faraday. There are also two Lockyers, though these are so close to one another that the confusion would seem to have arisen from an error in identification. Again, the

* *Breslau Mitteil.* vol. ii. 1903.

names of Argelander and Janssen have been given by Schmidt and Birt respectively to the same formation, as also those of Leverrier and Miller to another, and those of Hencke and Daniell to a third.

It is possible that careful search would reveal other instances of duplication. I mention these as having been noted in the course of my work.

The introduction of a new name has, in general, involved a change for those minor formations which are nearer to the newly named crater than to that by whose name they were previously known. These retain the old letters but take the new name. Thus, when the name Murchison was given by Birt, the adjacent crater Triesnecker A became Murchison A. This same crater, Murchison A, has been named Chladni by Schmidt, and is erroneously called Murchison by Franz.

When the name Flammarion was introduced Mösting A should, in accordance with precedent, have become Flammarion A. But, thanks to the researches of Dr. Franz, Mösting A is to the Moon what Greenwich is to the Earth, the one point from which others are measured, and such a change would be intolerable; but we are left with the anomaly that Mösting A, which is nearly fifty miles from Mösting, is actually on the wall of Flammarion.

Both capital and small letters are used to denote the minor formations; thus Ptolemæus A and Ptolemæus *a* are quite distinct, whilst in some cases a third form, a, is introduced. This is an obvious disadvantage, as great care is necessary to prevent errors in transcription. Mädler's rule was to use capital letters for measured formations, small letters for those which were unmeasured; Roman letters for depressions, Greek for elevations. But he did not adhere rigidly to these rules himself, and others have entirely neglected them. The rule with regard to capital and small letters is now quite unworkable, for it would involve a change of name when a previously unmeasured formation is measured, and moreover it would frequently be found that the corresponding capital had been already appropriated. The similarity of the capitals A and B in the two alphabets is another cause of confusion, though here again Mädler usually indicates a difference. Finally different letters are sometimes applied to the same crater in different maps, or the same letter to different craters.

Enough has been said to give an idea of the difficulties under which selenography labours, and further, as individual formations are studied and mapped, the number of small craters to be named may be increased twenty- or thirty-fold. It is eminently desirable that their designations should be allotted upon some uniform system.

If a remedy is to be found which will meet with universal assent—and nothing short of this would be a remedy at all—it is obvious that it must be the work of an international committee.

Hence the Council of the Royal Astronomical Society has passed a resolution that the International Association of Academies should be asked to nominate a committee to report upon the present state of Lunar Nomenclature, and to suggest a course of action for the future.

Part of the work of such a committee would be tedious, but would present no other difficulty. A list of all the cases of ambiguous nomenclature might be drawn up, and a decision taken as to which names should remain. It ought, also, not to be very difficult to devise rules for future guidance, and, if it were thought advisable to leave opportunities for the introduction of new names, to provide some simple machinery for the official sanction and publication of such introduction.

But the real difficulty would be to devise a means by which the decisions of the committee may be made intelligible to the world in general; to devise means by which selenographers may be enabled to identify with comparative ease the formation corresponding to any given name, or the name allotted to any given formation.

The ideal plan would be to prepare an accurate map, but this would seem to be a counsel of perfection. Schmidt spent thirty-four years in the preparation of his map, and we want a better. It is true that the photographs would to a certain extent diminish the labour; but even with these it would involve many years of patient work, whilst the knowledge, skill, and opportunity required to bring it to a successful issue are such as could rarely be found united in any one person.

It remains, then, to consider whether the photographs cannot be used directly, and I venture to put forward the following suggestions for criticism, in the hope that they may indicate a direction along which a solution may be ultimately found :—

If a series of four or five of the best modern photographs, showing the Moon under different illuminations, were enlarged to a diameter of from 12 to 18 inches, and the enlargements developed with impressed réseaux, so that the lines should appear in the same positions in all copies, it might be possible to identify a sufficient number of formations upon these and to give their positions in terms of réseaux coordinates. Two catalogues might then be formed, one so arranged that the name corresponding to any given formation could be at once ascertained, and the other so that the formation bearing a given name could be found. It is well known that photographs do not show anything like the amount of detail that can be seen with even a moderate telescope, but they do show a great deal. Mr. Hardcastle has partly measured more than 1800 small craters on one of Mr. Ritchey's exquisite negatives, and this by no means exhausts the number that could be identified on this one plate alone. The only part in which I should anticipate serious difficulty would be in the regions near the east and west limbs, of which it is not easy to get

photographs showing much detail. Possibly these might require special treatment.

Formulæ might be given for each plate for converting the réseaux coordinates into absolute selenographical coordinates, but the former would be more convenient for identification and for reference.

There are other questions which would also engage the attention of such a committee as has been proposed. Professor Shaler, writing as a "geologist and geographer," * has expressed the opinion that the present system of nomenclature is crude and inadequate; that the analogies suggested are often misleading; and that many of the more important features, such as capes, have been left unnamed. He suggests the appointment of just such a committee as is now advocated to undertake possibly the revision, and certainly the extension, of the present system.

Professor W. H. Pickering, again, has urged † that the existing names have been unfortunately allotted; that in many cases large and important areas have received the names of men who have done little for selenography, or even for astronomy, whilst many men who should be really commemorated are represented by small and insignificant craters. It is probably too late to alter this, but the criticism might well be considered by the committee.

On a New Method of Determining the Moon's Position photographically. By E. B. H. Wade, M.A.

(*Communicated by Professor H. H. Turner.*)

(1) Several methods have been proposed for determining photographically the Moon's position, either with a view to finding ephemeris errors or, given these, the longitude of a place. Amongst these methods we may mention that of Major Hills, R.E.,‡ in which a rigidly mounted camera is used to photograph the trails of suitable stars preceding the Moon, after which instantaneous exposures are made on the Moon itself, and finally further exposures are made for star-trails following the Moon. Again Professor Turner § has indicated a method of obtaining photographic transits which would be quite applicable to Moon culminations. Finally the same author has described ‖ an extremely direct method in which the Moon is photographed amongst the stars immediately surrounding it. Over-exposure of the Moon's image relatively to the stars is avoided by

* "A Comparison of the Features of the Earth and the Moon," *Smithsonian Contributions to Knowledge*, No. 1438, pp. 75, 76.

† *Harvard Annals*, vol. li. pp. 14, 15.

‡ *Mem. R.A.S.* vol. liii.

§ *Monthly Notices*, lvii. p. 349.

‖ *Monthly Notices*, lxiv. p. 19.

drawing an opaque diaphragm furnished with a narrow slit across the Moon's image during the whole period of exposure.

With regard to the first method, although it has the merit of great simplicity, yet it is subject to the inconvenience that a complete set requires at least two hours' work. During the whole of this time the camera must remain immovable, and as the diurnal motion is uncompensated the exposures must be timed with extreme precision. As Professor Turner has pointed out,* the methods of exposure on the Moon and stars are dissimilar, and this might lead to systematic errors. In any case the error in the deduced right ascension of the Moon is as great as the error in the time of exposure on the Moon.

With regard to the second method, it should be of a very high order of accuracy; but we are not, so far as I am aware, in possession of any actual results. I myself made some experiments in this direction in 1902, but was only partly successful, as I was employing a makeshift apparatus.

With regard to the third, if fog be successfully overcome it should enjoy all the accuracy of astrographic measurements. The method about to be described is put forward as an alternative one, and it is hoped to institute comparative experiments between the two.

(2) By means of double-image arrangements of mirrors it is possible to view the Moon in optical contact or proximity with stars which are in fact remote from it, and which in consequence are projected on a dark background. I have been working at intervals since 1901 November on methods of this kind, which are in fact extensions of the well-known method of observing the "lunar distance," and I have constructed an apparatus for *visual* observations on this principle, which is not yet, however, ready for publication. The object of the present note is to describe a photographic method by means of which the Moon's image is printed in the midst of stars at a distance of about 15° from it, so that all trouble from fog is avoided, and quite faint stars may be registered with instruments of small dimensions. All that is needed is an ordinary cœlostat and photographic camera; but the mirror of the cœlostat, instead of being worked to a true plane, is worked to a prism whose two faces are inclined at an angle of 7½°, and whose edge is parallel to the polar axis. When the camera is pointed at such an arrangement it can photograph two fields whose centres are distant from one another by 15° in right ascension. No apparatus not in ordinary use is necessary, except that a prism is substituted for the ordinary mirror.

(3) A camera is mounted at such a height that its optic axis passes horizontally through the centre of the mirror, so that one half of the object-glass is illuminated by one face of the prism and the other half by the remaining face. I arrange the circle of the cœlostat so that (for example) the preceding face of the

* *Monthly Notices*, lxiv. p. 19.

prism projects the Moon's image in the centre of the field of the camera, and hold a sheet of white cardboard in front of the object-glass, to prevent any light entering the camera, while I draw the shutter of the dark slide. A semi-oval patch of moonlight is seen on the cardboard. The shutter of the plate-holder having been withdrawn, I move the cardboard laterally until the object-glass is uncovered, except for that half which is concerned in forming the Moon's image. The semi-oval patch of moonlight on the cardboard makes this operation easy. The card is held in this position during two and a half minutes; during the whole of this time the plate is receiving light from stars reflected by the following face of the prism, but none from the Moon. The cardboard is now moved sharply, so as to uncover the whole object-glass for a fraction of a second, and then restored to its former position. The exposure through half the object-glass is continued for another two and a half minutes. On development the plate is found to have registered an instantaneous photograph of the Moon in the midst of star images which have been exposed for five minutes, and have right ascensions differing by about one hour from that of the Moon.

(4) In the actual experiments the mirror of the cœlostat had a diameter of only four inches. The best lens which I had at my disposal was taken from a 2-inch visual achromatic telescope by Dallmeyer. On June 18 (when the Moon's age was fifteen days) in each of two consecutive exposures I secured eleven stars, none of them brighter than the magnitude $6\frac{1}{2}$, *and there was no sign of fog.* The method would therefore appear to repay trial on a larger scale. Out of the eleven stars the following were identified :—

15 *Sagittarii.*	82 *Sagittarii.*
16 *Sagittarii.*	ρ^2 *Sagittarii.*
21 *Sagittarii.*	

On the 19th I obtained :—

Preceding the Moon.	Following the Moon.
v *Sagittarii.*	ι *Capricorni.*
ρ *Sagittarii.*	30 *Capricorni.*
	31 *Capricorni.*

But I am not at the present moment sufficiently equipped with maps or catalogues to identify the remaining stars, which, however, are certainly fainter than magnitude $6\frac{1}{2}$. That they are really stars is certain; for, the clock of the cœlostat being imperfectly adjusted, each is represented by a short trail parallel to those of the identified stars. I have not as yet the necessary apparatus for making precise measures of these images.

(5) The question will naturally suggest itself: How far does precision depend on the adjustments of the cœlostat? The only

essential function of the cœlostat is to make the star images stand still during the five minutes of exposure. A fuller discussion of this point will be given later. For the present it is enough to say that if we take two photographs, in one of which the Moon's image is projected on a field of stars following it, and in the other on a field of stars preceding it, the small errors, due to adjustment, can be eliminated and the angle of the prism determined. Owing to the great constancy of the angle of a prism, it may be desirable to determine it once and for all from star images without the intervention of the Moon.

(6) I have in conclusion to tender my best thanks to Captain H. G. Lyons, R.E., Director-General of the Survey Department, for providing facilities for this work and sanctioning its publication.

Helwan Observatory, Egypt:
1905 *July* 5.

NOTE.—Since the above was written I have obtained many other successful negatives with the apparatus described. The most interesting of these were taken in August in order to compare the ephemeris errors deduced with those given by the observations made at Helwan, Aswan, Edfu, and Chartas on the phases of the total eclipse of 1905 August 30.

Reproduction photographique des réseaux astrophotographiques. By Henry Bourget.

1. Les astronomes qui ont manié des réseaux tracés sur argent savent quelles précautions exige leur emploi et combien ils se détériorent rapidement. Les piqures qui se forment dans la couche d'argent finissent, malgré les retouches, par les rendre inutilisables. Il faut acheter un réseau neuf, l'étudier et dresser le tableau de ses corrections. C'est une dépense et une perte de temps. Il serait très désirable d'en avoir de plus résistants et d'un usage, pour ainsi dire, indéfini. Un autre avantage d'un pareil réseau serait la possibilité de l'imprimer sur les plaques, au châssis-presse, par contact parfait. Ce serait à la fois plus commode et plus précis que le mode d'impression actuellement employé.

Un pas important a été fait dans cette voie par M. Izarn quand il a décrit dans le Bulletin de la Carte du ciel le procédé permettant de recouvrir la couche d'argent d'une couche mince de gélatine bichromatée insolée et par suite dans un état presque

corné que l'on connait bien. C'est une excellente pratique, mais d'application un peu délicate.

Il m'a semblé qu'on rendrait service en cherchant à faire une copie photographique d'un réseau, assez précise pour permettre de l'utiliser à la place du réseau lui-même. Voilà plusieurs années déjà que je fais des essais dans cette direction. Je vais dire ce que j'ai obtenu.

2. Cette copie doit être, naturellement, de même sens que le réseau, c'est-à-dire à traits transparents sur fond noir. Il faut donc, pour cela, tirer une copie d'une première épreuve négative. Mais, d'autre part, il y a intérêt, pour diminuer les erreurs inévitables de copie, à réduire autant que possible le nombre des tirages. On est donc amené à essayer d'obtenir du premier coup une épreuve positive du réseau, en utilisant le renversement de l'image photographique par solarisation.

La partie délicate du procédé est d'obtenir une copie présentant le contraste maximum entre la transparence des traits et le noir du fond et d'éviter les tons gris uniformes si fréquents dans les images renversées.

Voici le procédé auquel je me suis arrêté, sur l'avis bienveillant de M. Izarn. Il a toujours réussi parfaitement, en observant les précautions que j'indique. On choisit une plaque sensible très rapide (Lumière Σ) sur glace de préférence. On l'expose au soleil 10 secondes fortement pressée derrière le réseau qu'on veut copier, dans un châssis-presse. On la développe ensuite dans un révélateur énergique, peu importe lequel du reste, tout bain fort réussissant bien. L'image commence par apparaître négative, puis se renverse, grise d'abord, le contraste entre les traits et le fond croissant graduellement. Il faut surveiller avec soin le développement et l'arrêter au moment où le contraste paraît le plus grand et avant que le plaque ne passe par une troisième état de grisaillement uniforme. On achève le traitement de la plaque comme à l'ordinaire.

Si l'on trouve que le fond, malgré le développement énergique, n'est pas assez noir, on peut renforcer la plaque. Voici un mode de renforçage qu'on peut répéter autant de fois que l'on veut et qui m'a bien réussi en cette circonstance. On commence par décrasser la plaque en la soumettant pendant quelques instants à la liqueur de Farmer [ferricyanure de potassium et hyposulfite de soude]. On lave, puis on la plonge dans le bain suivant :

Eau.	100 c.c.
Bichromate de potasse	2 gr.
Acide chlorhydrique	1 c.c.

et on l'y laisse jusqu'à ce qu'elle soit également blanche sur les deux faces. On la retire alors, on lave abondamment et on la développe à nouveau *en pleine lumière*.

J'ai l'honneur de présenter à la Société astronomique Royale,

en même temps que cette note, un spécimen de copie faite en suivant ces prescriptions, du réseau 8 cm. × 8 cm. que j'emploie à Toulouse pour les clichés de Nébuleuses et d'amas, photographiées au grand réflecteur de l'observatoire.

Pour qu'on puisse apprécier le degré de précision obtenu, je donne les résultats de quelques mesures faites sur le réseau et sur une copie.

	Intervalle des traits 11–14.		Intervalle des traits 40–43.	
	Réseau.	Copie.	Réseau.	Copie.
	7 tours, 507	7 tours, 504	7 tours, 498	7 tours, 495
	502	500	497	501
	506	501	496	499
	501	501	496	500
	500	500	500	502
Moyennes...	7 tours, 5032	7 tours, 5032	7 tours, 4992	7 tours, 4994

Le tour de vis vaut à peu près un millimètre. On voit que l'écart entre le réseau et la copie est négligeable pour le travail courant de la photographie astronomique.

Je signale, en terminant, un dernier avantage d'un telle copie. Sa valeur commerciale, pour ainsi dire, nulle, la rend accessible sans dépense à l'astronome amateur.

Toulouse: 1905 *novembre* 10.

Position of the Axis of Mars. By Professor Percival Lowell.

(*Communicated by A. C. D. Crommelin.*)

In 1905 the same course was pursued in the determination of the position of the Martian axis by measurement of the north polar cap as in the previous oppositions of 1903 and 1901. As the arctic spring haze lasted longer than in 1903, and the post-opposition phase invaded the north polar limb earlier, not so many observations could be secured. These began on April 7 and were continued to June 1, opposition having occurred on May 8. All the measures after this latter date were theoretically affected by the phase encroachment and those after May 17 sensibly so. The correction for this, so far as it is calculable from the difference between the tangent supposed taken on the limb and really taken along the phase ellipse, has been applied. The alteration due to lack of light there is no means of estimating.

Tabulated the measures follow :

Date.		M.S.T. h m	Position-angle. °	wt.	λ. °
April	7	16 24	128·2	4	297·5
	9	14 55	128·3	3	257·7
	12	16 8	128·9	4	248·5
	13	14 39	127·3	2	217·8
	15	14 18	125·5	3	194·8
		32	124·4	3	198·2
		37	126·1	2	199·4
	17	14 0	127·3	2	172·5
		50	125·5	3	184·7
		16 0	126·9	3	201·8
	19	14 31	124·3	3	162·2
		15 12	128·1	3	172·2
	24	14 14	126·4	4	113·7
	26	13 54	126·1	2	91·1
		14 30	127·0	2	99·9
	30	13 48	126·1	2	54·3
May	5	11 40	126·9	3	339·1
		12 12	127·1	4	346·9
	7	10 57	126·2	3	311·1
May	10	10 49	127·6	2	282·8
	11	10 40	128·8	3	271·8
		11 56	129·7	4	290·4
	12	10 36	129·9	4	262·1
		11 50	129·3	4	280·1
	16	11 32	130·4	3	240·6
	17	12 39	128·7	2	248·1
	21	11 39	128·0	3	198·3
	22	10 55	126·1	3	178·8
	23	10 57	124·0	2	170·4
	24	11 0	125·0	3	162·3
		20	125·7	5	167·2
		46	126·7	5	173·5
	26	9 49	126·4	4	127·3
		10 38	125·9	3	139·2
	30	11 18	129·5	4	113·5
		12 15	129·2	2	127·4

In the discussion three methods have been employed :

(1) *dp* has been found from the pre-opposition measures only ;
(2) from the measures to May 17 inclusive ;
(3) from all measures, those after opposition having had applied the correction to the tangential angle due to the phase ellipse.

The three resulting values of *dp* are :

$$(1)\ -1^\circ{\cdot}64 \pm 0^\circ{\cdot}22\ ;\ (2)\ -1^\circ{\cdot}49 \pm 0^\circ{\cdot}21\ ;\ (3)\ -1^\circ{\cdot}73 \pm 0^\circ{\cdot}20$$

With these several values of *dp*, P has been corrected for the corresponding epoch :

1	Epoch	1905 April 23	36°·66
2	„	1905 April 28	36·99
3	„	1905 May 4	36·97

and the resulting great circles successively compared with those from 1901 and 1903 to the following determinations of the position of the Martian axis :

		Axis R.A.	Axis Dec.	Tilt of Martian Equator to Martian Ecliptic.
		° ′	° ′	° ′
1	1905 Before Opposition and 1901	315 51	54 6	23 35
2	1905 Through May 17 and 1901	315 57	53 58	23 43
3	1905 All, Corrected and 1901 ...	315 47	54 11	23 29
1	1905 Before Opposition and 1903	317 9	54 17	23 59
2	1905 Through May 17 and 1903	317 28	54 9	24 11
3	1905 All, Corrected and 1903 ...	317 2	54 20	23 55
	And in addition:			
	1905 Before Opposition and 1903 before Opposition ...	317 18	54 18	24 2

There is a close accord *inter se* in both sets of 1, 2, and 3, showing that the corrections are not vital. Between the two sets, however, there is a difference difficult to explain.

	R.A.	Dec.	Tilt.
	° ′	° ′	° ′
The mean of 1901 and 1905 is:	315 52	54 5	23 36
that of 1903 and 1905:	317 13	54 15	24 2

For the position of the vernal equinox of the planet we have:

		R.A.	Dec.
		° ′	° ′
1	1905 Before Opposition and 1901	84 47	24 28
2	1905 Through May 17 and 1901	84 39	24 27
1	1905 Before Opposition and 1903	86 36	24 33
2	1905 Through May 17 and 1903	87 50	24 37

of which the means of the sets are respectively:

R.A.	Dec.		R.A.	Dec.
84° 43′	24° 27′	and	87° 13′	24° 35′

The data derived from 1901 and 1903 (Lowell Observatory Bulletin, No. 9) for epoch 1905 are:

	Axis R.A.	Axis Dec.	Tilt.	Vernal Equinox R.A.	Vernal Equinox Dec.
	° ′	° ′	° ′	° ′	° ′
1903 Expurgated and corrected for setting on phase ellipse and 1901	315 8	55 3	22 37	85 52	24 32
1903 Before and after Opposition, expurgated and corrected...	315 58	54 40	23 13	86 2	24 33

The means for all four sets, viz. 1901–1903, 1903 before and after opposition, 1901–1905, and 1903–1905, are:

Axis. R.A.	Axis. Dec.	Tilt of Martian Equator to Martian Ecliptic.	Martian Vernal Equinox. R.A.	Martian Vernal Equinox. Dec.
316° 3′	54° 31′	23° 22′	85° 57′	24° 32′

The result nearest to this is Lohse's, derived from measures on the north polar cap in 1884, 1886, and 1888, of which the mean is :

Axis. R.A.	Axis. Dec.	Tilt.
316° 45′	54° 31′	23° 39′

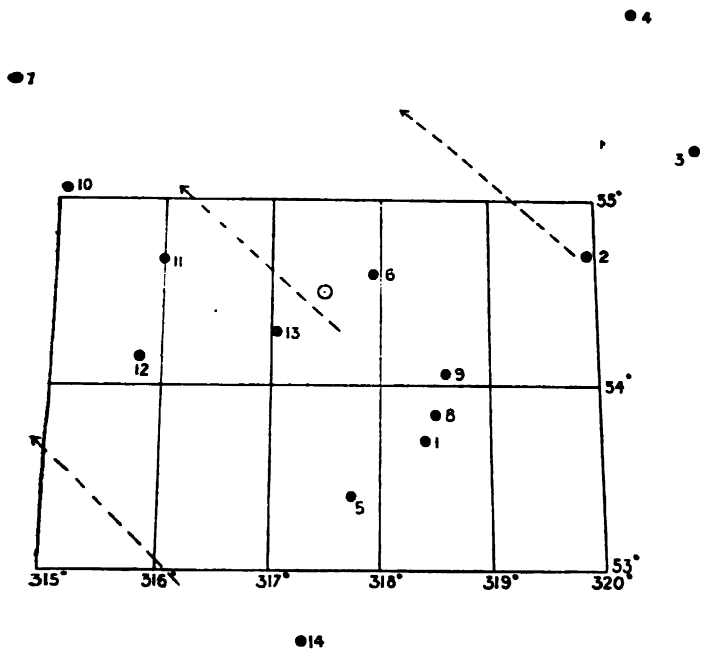
Schiaparelli's, Lohse's, and Cerulli's determinations have been completed and brought up to the epoch 1905 May 1 by taking account of the precession of the equinoxes. The correction for the Martian precession of the equinoxes has also been applied to the older determinations of the position of the axis of *Mars* to bring them down to date. This last as given by Struve, 7″·07 per annum, amounts only to six tenths of a minute in declination and three tenths in right ascension for twenty-six years. The results, together with Struve's and the writer's, are given in the following table :—

			Axis. R.A. ° ′	Axis. Dec. ° ′	Tilt of Equator to Martian Ecliptic. ° ′
1	S.	1877–1879 (Schiaparelli) ...	318 25	53 40	24 57
2	N.	1882–1884 „ ...	319 52	54 42	24 50
3	N.	1882–1886 „ ...	320 56	55 17	24 52
4	N.	1884–1886 „ ...	320 22	56 0	24 9
5	N.	1884–1886 (Lohse)	317 43	53 24	24 51
6	N.	1884–1888 „	317 52	54 36	24 3
7	N.	1886–1888 „	314 39	55 34	22 4
8	S.	1892–1894 „	318 31	53 51	24 51
9	S.	1896–1898 (Cerulli)	318 38	54 ·4	24 45
10	N.	1901–1903 (Lowell)	315 8	55 3	22 37
11	N.	1903 Before and after Opposition (Lowell)	315 58	54 40	23 13
12	N.	1901–1905 Complete corrected (Lowell) ...	315 47	54 11	23 29
13	N.	1903–1905 Complete corrected (Lowell) ...	317 2	·54 20	23 55
14		Struve (Satellites)	317 18	52 39	25 13

These several values have been plotted and appear in the following chart, the adopted mean position for the pole being denoted by the sign ⊙. The arrows indicate the direction of the pole of the Martian ecliptic.

Measures of the position of the cap in the drawings by the

writer in 1903 (Bulletin No. 18) show a correction to be needed to the ephemeris tilt, diminishing that tilt by 1°·7; thus making the value 23°·5 instead of 25°·2, as deduced and used in the ephemeris.



Position of the Pole of *Mars*.

The writer was therefore minded to see what Schiaparelli's drawings might have to say on the subject. He measured accordingly the drawings published by Schiaparelli in his fifth and sixth Memoirs, the only ones available for the purpose, and found that they placed the centre of the cap as follows:

1886.

Drawing No.	Lat. Centre of Cap.	Position of Pole as in Centre of Cap on the Disk.	Ephemeris Pole on the Disk.	Difference.	λ.
I.	67°·3	22°·6	21°·8	− 0°·8	Not given on drawings,
II.	66·4	23·6	21·8	− 1·8	
III.	66·8	23·2	21·9	− 1·3	
IV.	68·2	21·8	21·9	+ 0·1	
				− 3·8	
		Mean ...	... ...	− 0·9	

1888.

Drawing No.	Lat. Centre of Cap.	Position of Pole as in Centre of Cap on the Disk.	Ephemeris Pole on the Disk.	Difference.	λ.
VII.	70°·4	19°·6	24°·7	+ 5°·1	10
VIII.	66·7	23·3	24·8	1·5	350
IX.	68·9	21·1	24·8	3·7	340
X.	66·7	23·3	24·8	1·5	320
XI.	67·9	22·1	24·8	2·7	300
XII.	70·6	19·4	24·8	5·4	300
XIII.	67·1	22·9	24·9	2·0	240
XIV.	67·8	22·2	24·9	2·7	220
				24·6	
		Mean ...	... ...	+ 3·1	

It might be argued that the drawings of the latter opposition are the better as with each opposition a draughtsman grows more proficient. But assuming all to be of equal weight, we have from the drawings of both oppositions an excess of tilt of ephemeris over observation of 1°·7, supposing the centre of the cap upon the pole. Now, in his *Memoria IV.*, Schiaparelli gives for the position of this centre a displacement of 2°·69 in λ 323°·5, and, in his *Memoria V.*, of 1°·269 in λ 295°·1. Comparing the longitudes of the drawings in 1888, we see that in most of them the centre was on the south side of the pole, which would increase the apparent polar tilt, not decrease it. The irradiation would do likewise. That the drawings indicate a tilt less than the ephemeris in spite of both these factors strengthens the conclusion that that tilt is too large. Indeed, in the future the tilt is more likely to be yet further reduced than increased.

From all these determinations the most probable position of the pole of the Martian equator seemed to the writer, after consultation with Mr. Crommelin, to be :—

R.A. 317°·5 and Dec. 54°·5. Epoch 1905. Tilt of Martian Equator to Martian Ecliptic 23° 59′.

The above value has been adopted for physical ephemerides of the planet in the British *Nautical Almanac*, beginning with that for the opposition of 1909.

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On the Conditions determining the Formation of Cloud-spheres and Photospheres. By Arthur W. Clayden, M.A.

In the course of an investigation of the conditions under which clouds may be formed in our own atmosphere certain considerations presented themselves which seem equally applicable to the conditions which determine the position of a stellar photosphere in the mass of a star.

As the spectrum of a star is to a great extent dependent upon the position of the photosphere it seems possible that a survey of these points may help to clear up some of the difficulties attending the interpretation of spectral details.

To begin with it is necessary to ask that it may be taken for granted—

1. That the photosphere of a star is the upper surface of a stratum of clouds.

2. That those clouds are caused by the condensation of some substance from the state of vapour to that of small solid or liquid particles.

3. That the condensation is due to cooling produced by expansion brought about by the ascent of vapour-charged convection currents.

4. That the cooling effect of expansion follows the same general thermodynamic law as is the case in our own atmosphere.

It is true that under the high pressures and temperatures of a star the gradation of temperature may be considerably modified. The transference of heat from one stratum to a higher by conduction and radiation should tend to equalise temperatures, but the increased viscosity due to pressure should tend in the opposite direction. Hence a curve showing the relations of temperature and pressure is not likely to differ very greatly from one plotted in accordance with the expression

$$\frac{\log t - \log t'}{\log p - \log p'} = \frac{\gamma - 1}{\gamma}$$

in which t is the absolute temperature at a pressure p, and t' is the absolute temperature at the reduced pressure p'; γ is, of course, the ratio of the two specific heats.

In order to argue from the known to the unknown, let us first consider the case of planetary bodies surrounded by an atmosphere consisting wholly of water, a substance whose temperature-pressure relations are well understood.

At temperatures far below freezing-point ice gives off vapour which exerts a certain maximum pressure. As the temperature rises this maximum pressure increases more and more rapidly. This goes on until 365° C. is reached, at which point the maximum pressure is 200·5 atmospheres. If at any temperature the pressure be less than the maximum, evaporation will take place;

and conversely if the pressure exceed the maximum, condensation will follow until the pressure is reduced to that value.

We can then plot a curve showing the maximum pressures for all temperatures. Let this be done, taking temperatures as abscissæ and pressures as ordinates.

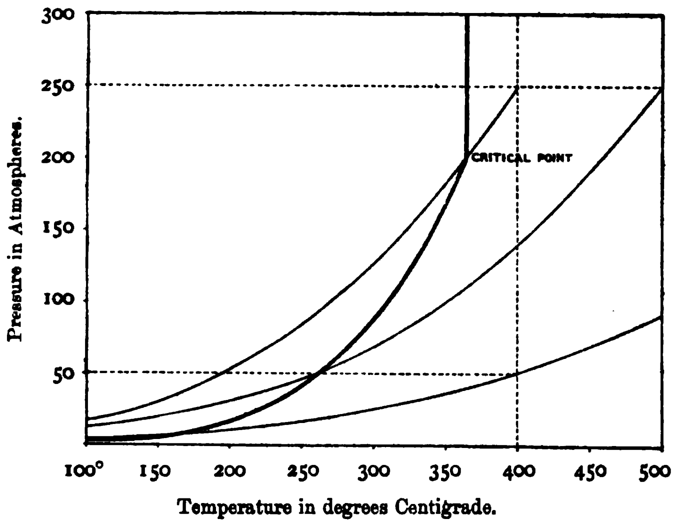


Fig. 1.—Condensation Curve for Water Vapour.

We find the curve rises at first very slowly, and at 100° C. it shows a pressure of one atmosphere. It then turns upwards more and more rapidly until it reaches 365° C. and 200·5 atmospheres. This is the critical point; and if the temperature be higher no increase of pressure can possibly bring about liquefaction. The curve may be regarded as giving the pressures and temperatures of condensation. If, then, the pressure is greater than 200·5 atmospheres, condensation will be effected at the critical temperature. The curve must therefore turn vertically upwards.

Let us now assume that the masses of atmosphere and planet are such that the pressure on the solid surface is 250 atmospheres, and that this surface has a temperature of 400° C. No liquid water can exist on such a surface, but condensation will occur at a certain height.

If the curve of decreasing temperature be plotted, using the expression quoted and giving to γ the proper value for water vapour—namely, 1·3—it will be found that this curve will cut the condensation line very near the critical point, at which temperature and pressure cloud-production will begin.

Suppose, next, that the surface temperature is increased to

500° C. If a similar curve be now plotted it will be found to cut the condensation line at about 50 atmospheres and a temperature of only 260° C.; that is to say, the effect of increasing the surface temperature of the planet is, not only to drive the cloud-level further up in the atmosphere, but to lower the temperature at which its formation begins.

Again, suppose the surface temperature to be 400° C. but the pressure only 50 atmospheres. The curve then cuts the condensation line at about 160° C. and a pressure of less than 10 atmospheres.

It thus appears that the result of suitably diminishing the mass of a planet may be to produce exactly the same effect upon any cloud-sphere by which it is surrounded as would be brought about by increasing its temperature; or that a hot planet of large mass might present exactly the same features as a cooler and smaller one.

If we imagine the planetary atmosphere to contain other non-condensible gases this will not affect the conclusions. The changes due to alterations of temperature and pressure will still be in the same direction, and the diagram will serve equally well if we remember that it relates only to the pressures and temperatures of the water vapour present. The actual pressures in the whole atmosphere could be computed by calculating them for the other substances and adding those values.

An inspection of the diagram shows that no cloud-sphere could possibly have a higher base temperature than 365° C. This is one point worth noting.

Next it is evident that if our eyes were so constituted that we could see the radiations emitted from the outer surfaces of such cloud-spheres they would become true photospheres; and if the distances were great enough we should see these supposed planetary bodies as star-points. If two of them had their cloud-spheres at similar positions in their atmospheres they should present similar spectral features. We should then class them together, although they might really owe their apparent similarity to their true diversity.

Finally it is obvious that a determination of the temperature of the outer surface of the cloud-sphere would be no measure whatever of the temperature of the solid planet beneath.

It is not necessary to point out that these conclusions have an important bearing on the cloud-spheres surrounding the actual planets.

It seems only reasonable to attempt to apply them also to the stars.

Now it is not necessary to make any assumption as to the nature of the substance which makes up the cloud-particles of a stellar photosphere, nor is it necessary to assume that all photospheres are due to the same body. Whatever the substance concerned its condensation-curve would probably present features

similar to those of all bodies for which the requisite data are obtainable.

The argument, however, will be clearer if we start with the assumptions that all photospheres are due to the same substance, and that that is the element carbon. It will be easy later on briefly to consider other possibilities.

We have no measurements of the vapour-pressures of carbon. But there seems some reason to think, from the phenomena of the electric arc, that the vaporisation temperature under one atmosphere pressure is about 3770° absolute. This, then, will correspond to 373° absolute, the boiling-point of water under one atmosphere.

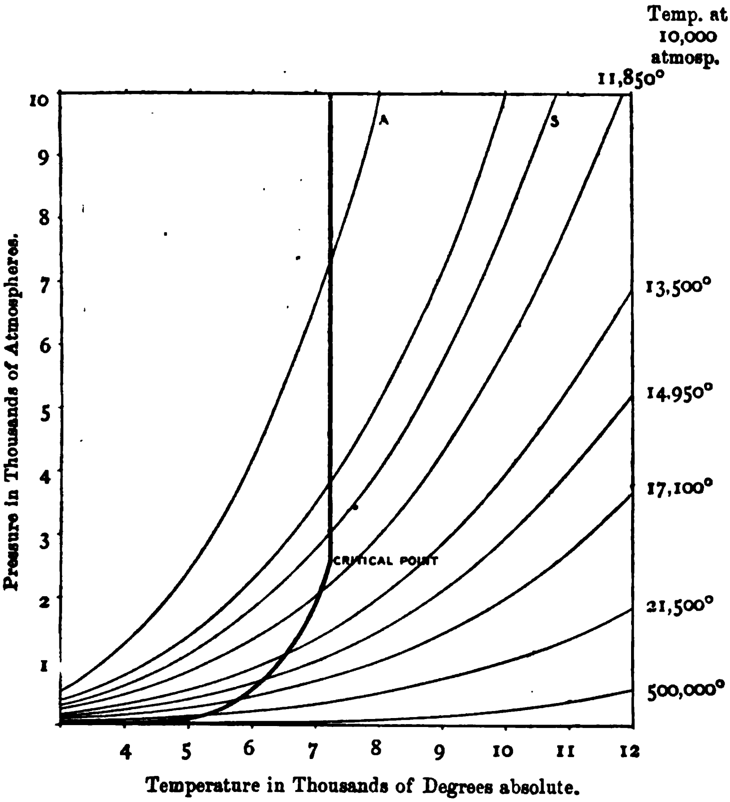


FIG. 2.—Hypothetical Curves for Carbon Vapour.

If we can get some idea as to the critical temperature we can then draw a curve resembling the known curve for water, and feel tolerably sure that our proceedings are reasonable. Messrs.

Wilson and Gray estimated the temperature of the solar photosphere at 6900° C.; but this is the upper surface of the cloud stratum, which must be cooler than the base. Hence if we take 7200° absolute as the critical temperature we can feel sure that we are at least within the mark, and may be a long way within it.

The difference between 3770 and 7200 is about thirteen times as great as that between 373 and the critical temperature for water. Hence if the condensation-curve for carbon is similar to that for water the critical pressure should be about 2600 atmospheres. If we connect the two points thus fixed by a curve resembling that for water it will serve our purpose, since neither the exact temperatures nor pressures are material to the issue, which rests only on the supposition that the vapour-pressures and temperatures for the photospheric substance can be represented by some curve of the usual type.

Let us draw the curve, and again, for simplicity, consider only the pressures due to the carbon vapour.

Before drawing the curves to represent the changes of temperature and pressure in the stellar mass we are confronted with another unknown—namely, the value to be assigned to γ. According to the determinations of this quantity yet made, it appears that elementary bodies whose molecules are monatomic give a value 1·66; those whose molecules are diatomic give 1·4 to 1·3; while polyatomic molecules give values decreasing with the complexity, but always greater than unity. At stellar temperatures it seems unlikely that there will be polyatomic molecules, so that if we take 1·5 as a working value we shall not be far wrong. Moreover it will soon be evident that a change in the value of γ will in no way affect our general conclusions, but will only modify the numerical examples which serve the purpose of making the argument clearer.

Let us now imagine six stars in which the pressure of 10,000 atmospheres is reached at 8000°, 10,000°, 11,850°, 14,950°, 21,500°, and 500,000° respectively. Plot the curves of descending temperature and pressure as we pass outwards as before. The results may be tabulated thus :—

Temp. at p = 10,000.	Condensation Pressure.	Condensation Temperature.
8000	7400	7200
10000	3850	7200
11850	2150	7050
14950	730	6250
21500	130	5250
500000	30?	4400

The table shows that if the initial pressure be far above the critical the result of increasing the initial temperature is to drive the photosphere into regions of diminished pressure. So long as

the pressure of condensation is above the critical, the temperature at which condensation begins remains unaltered; but as soon as this point is passed, and the curved part of the condensation line is reached, the temperature at which the clouds are formed begins to fall; that is to say, the effect of raising the internal temperature is to drive the photosphere further *out, and to cool it.*

Again, let us imagine that a temperature of 10,000° is found with pressures of 10000, 8000, 6000, 4000, 2000, and 200 atmospheres respectively, and tabulate the results as before.

Initial pressure t = 10,000.	Condensation Pressure.	Condensation Temperature.
10000	3850	7200
8000	3050	7200
6000	2150	7050
4000	1150	6550
2000	420	5850
200	30 ?	4400

The sequence of changes is exactly similar, and the conclusion is that, if the initial temperature is constant, decrease of pressure will produce the same effect as increase of temperature.

Now the pressure at any point is determined by gravity and the mass of the superincumbent gases. It therefore appears that no carbon photosphere can have a higher temperature than the critical, and that the hotter photospheres must be those most deeply seated, or surrounding the most massive stars.

Deep-seated photospheres must mean heavy absorption, high photospheres little absorption.

Inspection of the diagram reveals a number of interesting points, and it is easy to see how the spectra of stars should be modified by altering the ratio of temperature and pressure. Call this $\frac{T}{P}$.

Let us at the outset give this expression a very high value, so high as to make the curve on the scale of our diagram raised very little above the line of no pressure. Such a star would have no photosphere. If the temperature were suitable small particles of incandescent carbon would be dispersed here and there in a thin mist at a high level. They would be unable to hide the radiation from gases at lower levels or to reverse the light from those among which they were spread. Such stars would be bright-line stars in which the lines would be mixed with a faint continuous spectrum which would begin with a dim radiance in the yellow-green.

As we reduce the ratio $\frac{T}{P}$ the dim radiance will spread and brighten, since condensation under higher pressure means a higher temperature. The mist stratum of the bright-line star

should then pass through denser stages into the condition of a discontinuous stratum of bright photospheric clouds still high up though lower than before. The bright clouds will be overlaid by those gases which lie highest, giving a spectrum showing the dark lines due to absorption. But with a discontinuous stratum of cloud there must be convection. Rising currents will make the clouds, descending currents the interspaces. The light, then, from the descending spaces should be bright lines corresponding with those which are reversed above the clouds.

If we now bear in mind the fact that a star spectrum is an integration of the whole light from the stellar surface, it is easy to see that the bright-line spectrum may be brighter than the continuous ; it may be equally bright or it may be less brilliant. If the convection movements were slow the respective results would be bright lines on a continuous background, continuous spectrum alone, or a simple absorption spectrum. It is, however, not likely that all the lines would behave alike, and the result should generally be a white or helium star showing some lines bright and others reversed.

If we may suppose the convection currents sufficiently rapid, then the bright lines due to descending currents should be shifted towards the red, while other bright lines from deeper layers might be undisturbed. We should then have some bright lines fringed on their more refrangible sides by dark companions.

Decreasing the ratio still further the spaces between the cloudlets will close up until we have the complete helium star.

Further progress will yield a yet brighter and hotter photosphere sinking step by step beneath stratum after stratum of gases. As the background gets brighter, helium absorption, having little intensity, becomes less and less obvious. Hydrogen absorption, on the contrary, becomes more and more extensive until it in turn becomes secondary to the absorption due to metallic vapours.

The curves showing the temperature and pressure at which condensation takes place indicate steadily rising pressure, and rising temperature (and, therefore, intrinsic brightness) until the critical point is reached. From this point no further change in $\frac{T}{P}$ can alter the temperature of the photosphere. As it sinks lower and lower the density of absorption increases. If the metallic-line spectrum of the Sun may be supposed to be formed under the conditions represented by the curve S, on passing to the next cooler line we might have the denser absorption of *Arcturus*.

If the ratio $\frac{T}{P}$ be still smaller we come to the curve A. Here the photosphere is still deeper. The outer parts of the superincumbent gases are much cooler, and compound vapours may be formed. If so, we should expect that the absorption should

consist of metallic lines, flutings, and general absorption of the kind known as smoke-veil; for instance, *α Orionis* and *Antares*.

Continuing the process, such a spectrum should grow in intensity until the light of the photosphere should be hidden by superincumbent vapours, or even non-luminous clouds formed by condensed metals and compounds. The last glimpse of the incandescent depths should be a dull-red glow.

Such, then, seems to be the normal history of a star.

There is, however, a special case.

Suppose $\frac{T}{P}$ is very high, but that its large value is due to extreme heat, and that P is itself large.

The result should be a very dense gaseous nucleus which should give a continuous spectrum, and therefore act as a deeper-seated photosphere whose light would be veiled by absorption in which that due to carbon vapour would be a conspicuous feature; but metallic lines would also be present, and if the absorption were great, or the intrinsic brightness of the continuous spectrum small, some of the strong metallic lines would stand out as bright lines—carbon stars. Such stars should pass through the normal sequence as a result of declining temperature, which may explain the former redness of *Sirius*.

It thus appears that bright-line white stars should be associated with nebulæ; that white stars being due to the greatest range of conditions should be most numerous, especially among the smaller stars; that solar stars should be next in order of frequency, and should form a larger proportion of the massive stars; that stars with fluted spectra should be comparatively few in number, and should as a rule be massive. Finally carbon stars, demanding exceptionally high pressure and temperature, should therefore be rare and vast.

There are several other deductions which may be drawn.

First, if a binary is formed by the fission of a single star. If the division is equal both stars should be white, or both solar, or beyond. If unequal and differing to a sufficient extent, the smaller would adhere to a Sirian spectrum long after the larger and less cooled had passed into the solar stage or beyond; as, for instance, *β Cygni*.

Secondly, any determination of the temperature of a photosphere is no guide to the temperature of the star-centre. Neither is the position of the photosphere as shown by the absorption much help. It is possible to have a large hot star showing exactly the same spectrum as a much smaller and cooler one. The ratio $\frac{T}{P}$ may be identical.

So far it has been assumed that carbon is the cause of all photospheres. It is of course possible that different stars may be differently constituted, and that different elements may play similar parts. But all the evidence of the spectroscope indicates a cosmic distribution of the elements best known to us. Moreover

a moment's thought will show that all that has been said in reference to a carbon photosphere will apply with equal force to any substance whatever. If, then, we can have photospheres formed of some heavier atoms, they should be situated deeper in the mass of the star, and should be overlaid by carbon, which should either form a higher photosphere in turn or should betray its presence by absorption. We ought, then, to have as great a variety of carbon stars as we have of other types. The fact of the rarity of carbon stars is one of the strongest evidences that it is pre-eminently *the* photospheric element. However this may be, the main conclusions here set forth remain unaffected, because they hold good for any substance which forms a photosphere, granting only the four postulates with which we started, and that this substance behaves like all others whose condensation-curves are known.

Observations of Comet a 1903 from Photographs taken with the 30-inch Reflector of the Thompson Equatorial and the Astrographic Equatorial of the Royal Observatory, Greenwich.

(*Communicated by the Astronomer Royal.*)

Date and G.M.T. 1903.			Apparent R.A.	Apparent Dec.	Corr. for Parl. R.A.	Corr. for Parl. Dec.	log Δ.
	d	h m s	h m s	° ′ ″	s	″	
Jan.	28	5 54 31	23 7 51.38	4 30 20.5	+.17	+4.0	0.2130
Feb.	9	6 6 1	23 24 31.04	8 4 53.5	.20	4.1	0.1945
	9	6 19 59	23 24 31.93	8 5 2.7	.21	4.1	0.1945
	10	6 9 38	23 26 5.16	8 24 42.4	.21	4.1	0.1906
	10	6 24 14	23 26 6.61	8 24 59.6	.21	4.2	0.1906
	11	6 14 36	23 27 40.86	8 44 54.1	.21	4.2	0.1865
	11	6 25 21	23 27 41.67	8 45 4.0	.22	4.2	0.1865
	12	6 22 13	23 29 18.78	9 5 27.7	.22	4.2	0.1823
	17	6 24 41	23 37 50.76	10 51 55.8	.24	4.4	0.1587
	17	6 31 55	23 37 51.31	10 52 2.7	.24	4.4	0.1587
	18	6 22 16	23 39 38.30	11 13 58.2	.24	4.4	0.1534
	23	6 33 58	23 49 3.07	13 7 0.6	.27	4.8	0.1235
	25	6 33 46	23 52 59.49	13 52 30.8	.28	4.9	0.1098
	26	6 34 36	23 54 59.78	14 15 4.9	.29	5.0	0.1024
Mar.	3	6 35 24	0 5 11.79	16 0 47.3	.34	5.7	0.0439
	6	6 44 15	0 11 14.71	16 51 31.8	.35	5.9	0.0334
	11	6 53 4	0 20 12.23	17 23 25.6	.44	7.5	9.9348
	11	7 7 58	0 20 13.22	17 23 20.5	.45	7.6	9.9348
	11	7 25 59	0 20 14.34	17 23 17.6	.44	7.8	9.9348
	12	6 54 17	0 21 40.65	17 17 0.6	.46	7.8	9.9208
	13	6 55 55	0 23 0.06	17 4 44.4	.48	8.1	9.9048
	15	7 4 20	0 25 8.11	16 19 43.3	.51	8.9	9.8730
	16	6 59 24	0 25 54.72	15 45 48.7	+.53	+9.2	9.8570

The photographs up to and including the first on March 11 were taken with the reflector, the remainder with the Astrographic telescope. From January 28 to February 17 one exposure, and from February 18 to March 16 two exposures were given on each plate. Fuller details of these observations will be given in the Greenwich volume for 1904.

On the Astronomical Observations recorded in the "Nihongi," the ancient Chronicle of Japan. By E. B. Knobel.

Our knowledge of the *Nihongi*, which is the standard native history of ancient Japan, is derived from the translation made by Mr. W. G. Aston, which was published by the Japan Society a few years ago.

The *Nihongi* purports to be a history of Japan from the earliest mythological times to the year A.D. 697.

It contains the record of several astronomical observations, which are not without interest.

The observations consist of records of "Eclipses of the Sun and Moon," "Occultations of Stars and Planets," "Conjunction of Planets," "Apparition of Comets and Meteors," and two observations apparently of the Aurora Borealis.

The period covered by these observations is from the year A.D. 620 to 696.

The chronology of the earlier part of the *Nihongi* has been shown by several authorities to be entirely unreliable, and indeed Bramsen does not hesitate to assert that the fictitious dates therein ascribed to events, constitute one of the greatest literary frauds ever perpetrated. Though the above remark applies more particularly to chronicles before A.D. 600, it is of importance to critically examine the dates given to the astronomical events.

This is attended with some difficulty on account of the complicated chronological system in use in Japan, and which was borrowed entirely from China.

The elements of Japanese chronology are succinctly described by Mr. Kinoshita in his interesting little book, *Ancien Japon*, and also by the late Mr. Williams, the former assistant-secretary of the Royal Astronomical Society, in his work on "Chinese Observations of Comets"; but for the precise reconciliation of dates, the *Japanese Chronological Tables* of Bramsen, published at Tokio in 1880, though they go no further back than A.D. 645, are quite indispensable.

The year was a lunar year, consisting of twelve months of twenty-nine or thirty days; but in order to establish some correspondence between the months and the seasons, an additional month was intercalated every thirty-three months, or seven intercalary months in the lunar cycle of nineteen years. Common years had therefore 354 days, and embolismic years 383 or 384 days. The rules for determining the date of an intercalary

month are too complicated to be given here; but roughly, when the discrepancy between the civil and the solar years exceeds half a month, a correction is necessary, and an intercalary month is made. The months were designated by their ordinal numbers, but the intercalary month received the ordinal number of the preceding month. It is thus obvious that there is here a great possibility of error in reducing a date in Japanese or Chinese records to European chronology.

On this point the sexagenary cycle of years, of months, and of days, instituted by the Chinese in very ancient times, and continued by them and the Japanese to the present day, affords a means of checking dates with considerable certainty.

The commencement of the year was never coincident with January 1, but ranged from January 20 to February 18; the fact being that the year began with the new moon following the first new moon after the winter solstice.

The sexagenary cycle was formed by the combination of one series of twelve signs, named after the signs of the zodiac, called in Japanese Ju-ni-shi, and a second series of ten signs called Jikkan.

Sexagenary Table.

1.	甲子	21.	甲申	41.	甲辰
2.	乙丑	22.	乙酉	42.	乙巳
3.	丙寅	23.	丙戌	43.	丙午
4.	丁卯	24.	丁亥	44.	丁未
5.	戊辰	25.	戊子	45.	戊申
6.	己巳	26.	己丑	46.	己酉
7.	庚牛	27.	庚寅	47.	庚戌
8.	辛未	28.	辛卯	48.	辛亥
9.	壬申	29.	壬辰	49.	壬子
10.	癸酉	30.	癸巳	50.	癸丑
11.	甲戌	31.	甲午	51.	甲寅
12.	乙亥	32.	乙未	52.	乙卯
13.	丙子	33.	丙申	53.	丙辰
14.	丁丑	34.	丁酉	54.	丁巳
15.	戊寅	35.	戊戌	55.	戊午
16.	己卯	36.	己亥	56.	己未
17.	庚辰	37.	庚子	57.	庚申
18.	辛巳	38.	辛丑	58.	辛酉
19.	壬午	39.	壬寅	59.	壬戌
20.	癸未	40.	癸卯	60.	癸亥*

* It is preferable to use the Chinese characters rather than the words in Roman letters, on account of variations in orthography.

Months and days, like years, are counted by sexagenary cycles independently of each other.*

The Japanese call, under this system, the designation in the cycle the E-to † of the year, or month, or day. Intercalary months have no E-to. The E-to of the months for the Ju-ni-shi sign is always as follows :—

1st month	Tora	寅	7th month	Saru	申
2nd „	U	卯	8th „	Tori	酉
3rd „	Tatsu	辰	9th „	Inu	戌
4th „	Mi	巳	10th „	I	亥
5th „	Muma	午	11th „	Ne	子
6th „	Hitsuji	未	12th „	Ushi	丑

The following table from Bramsen's work may be useful :—

Perpetual Table showing the E-to of any Japanese Month.	If the Year from Jimmu-Tenno, B.C. 660, or the corresponding European Year, ends in				
	1 or 6.	2 or 7.	3 or 8.	4 or 9.	5 or 0.
1st month	27	39	51	3	15
2nd ..	28	40	52	4	16
3rd „	29	41	53	5	17
4th „	30	42	54	6	18
5th „	31	43	55	7	19
6th „	32	44	56	8	20
7th „	33	45	57	9	21
8th „	34	46	58	10	22
9th „	35	47	59	11	23
10th „	36	48	60	12	24
11th „	37	49	1	13	25
12th „	38	50	2	14	26

* The Chinese sexagenary cycle of years was included by Ulug Beigh in his Samarcand Tables, 1437, and will be found also in the valuable chronological tables given by Johannes Gravius at the end of his *Epochæ Celebriores Ulug Beigi*, 1650.

† The name E-to is derived from the fact that the terminations of the Japanese names of the ten signs of Jikkan are alternately -e and -to, thus: Kinoe, Kinoto, Hinoe, Hinoto, &c.

The following are the astronomical records in order of subject :—

Eclipses of the Sun.

1. "36th year of Emperor Suiko, A.D. 628, spring, 3rd month, 2nd day. There was a total eclipse of the Sun."

The first day of the first month was February 10, and the second day of the third month was April 10. Oppolzer, in his *Canon der Finsternisse*, gives a total eclipse of the Sun, with the central line running through Japan, on April 10, $0^h\ 49^m{\cdot}7$ G.M.T.

2. "8th year of Emperor Jomei, A.D. 636, spring, 1st month, 1st day. There was an eclipse of the Sun."

The first day of the first month was February 12. There is no eclipse in Oppolzer's table which can possibly accord with this date.

3. "9th year of Emperor Jomei, A.D. 637, spring, 3rd month, 2nd day. There was an eclipse of the Sun."

The first day of the first month was February 1. The second day of the third month was April 2. Oppolzer gives a total eclipse of the Sun, with the central line running through Japan, April 1, $0^h\ 3^m$ G.M.T.—a discrepancy of one day.

4. "9th year of Emperor Temmu, A.D. 680, winter, 11th month, 1st day. There was an eclipse of the Sun."

The Shūkai quotes a statement that this eclipse was of 9½ tenths, or nearly total." The first day of the eleventh month was November 27. Oppolzer's table gives an annular eclipse of the Sun, with the central line passing through Japan, on November 27, $3^h\ 13^m{\cdot}4$ G.M.T.

5. "10th year of Emperor Temmu, A.D. 681, winter, 10th month, 1st day. There was an eclipse of the Sun."

The first day of the tenth month was November 16. Oppolzer's table shows an annular eclipse of the Sun, with the central line passing through Southern China, on November 16, $2^h\ 24^m$ G.M.T.

6. "5th year of Emperor Jitō, A.D. 691, winter, 10th month, 1st day. There was an eclipse of the Sun."

The first day of the tenth month was October 27. Oppolzer's table gives an annular eclipse of the Sun, visible in Japan, October 27, $3^h\ 1^m{\cdot}9$ G.M.T.

7. "7th year of Emperor Jitō, A.D. 693, 3rd month, 1st day. There was an eclipse of the Sun."

The first day of the third month was April 11. Oppolzer gives an annular eclipse of the Sun April 11, $10^h\ 44^m$ G.M.T., visible only as a partial eclipse in Japan.

8. "7th year of Emperor Jitō, A.D. 693, 9th month, 1st day. There was an eclipse of the Sun."

The first day of the ninth month was October 5. Oppolzer gives a total eclipse of the Sun, with the central line running through South China, on October 5, $8^h\ 2^m{\cdot}1$ G.M.T.

9. "8th year of Emperor Jitō, A.D. 694, 3rd month, 1st day. There was an eclipse of the Sun."

The first day of the third month was March 31. Oppolzer gives a partial eclipse of the Sun March 31, $11^h\ 19^m{\cdot}7$ G.M.T.

10. "8th year of Emperor Jitō, A.D. 694, 9th month, 1st day. There was an eclipse of the Sun."

The first day of the ninth month was September 25. Oppolzer gives a partial eclipse of the Sun, September 24, $22^h\ 47^m{\cdot}3$ G.M.T. The correction for longitude makes the *Nihongi* date correct.

11. "10th year of Emperor Jitō, A.D. 696, autumn, 7th month, 1st day. There was an eclipse of the Sun."

The first day of the seventh month was August 4. Oppolzer gives an annular eclipse of the Sun, which could only be visible as a partial eclipse in Japan, August 3, $17^h\ 13^m{\cdot}6$ G.M.T. Here, again, the difference of longitude makes the *Nihongi* date correct.

Eclipses of the Moon.

1. "2nd year of the Emperor Kōgyoku, A.D. 643, 5th month, 16th day. There was an eclipse of the Moon."

The sixteenth day of the fifth month was June 8. In Oppolzer's table we find an eclipse of the Moon on June 7, $23^h\ 7^m$ G.M.T., which corrected for longitude agrees with the *Nihongi*.

2. "9th year of the Emperor Temmu, A.D. 680, 11th month, 16th day. There was an eclipse of the Moon."

The sixteenth day of the eleventh month was December 12. Oppolzer gives an eclipse of the Moon December 11, $14^h\ 8^m$ G.M.T., and the *Nihongi* date is correct.

Occultations.

1. "12th year of Emperor Jomei, A.D. 640, spring, 2nd month, 7th day. A star entered the Moon."

The seventh day of the second month is March 6.

2. "1st year of Emperor Kōgyoku, A.D. 642, autumn, 7th month, 9th day. A guest-star entered the Moon."

The ninth day of the seventh month is August 10.

3. "10th year of Emperor Temmu, A.D. 681, 9th month, 17th day. The planet *Mars* entered the Moon."

The seventeenth day of the ninth month is November 3.

Conjunction of Planets.

"6th year of Emperor Jitō, A.D. 692, autumn, 7th month, 28th day. On this night *Mars* and *Jupiter* approached and receded from one another four times in the room of one pace, alternately shining and disappearing."

The twenty-eighth day of the seventh month was September 14.*

* Very close conjunctions of *Mars* and *Jupiter* are recorded, A.D. 498, 509, 1170, 1591.

Comets.

"6th year of Emperor Jomei, A.D. 634, autumn, 8th month. A long star was seen in the south. The people of that time called it a besom-star. Hahaki-boshi or Hōki-boshi is the present name for a comet."

The eighth month began August 30. In Williams's *Comets observed in China* a comet is described in *Ma-twan-lin* as being seen, A.D. 634 September 22, in the constellation *Aquarius*, and which on October 3 was no longer visible.

"7th year of Emperor Jomei, A.D. 635, spring, 1st month. The besom-star went round and was seen in the East."

The date of the first day of the first month is January 24. This implies the reappearance of the 634 comet. It is not mentioned in the Chinese annals.

"11th year of Emperor Jomei, A.D. 639, 1st month, 26th day. A long star appeared in the north-west. Priest Bin said it was a besom-star. When it appeared there was famine."

The twenty-sixth day of the first month is March 6. The Chinese *Ma-twan-lin* records a comet, A.D. 639 April 30, as being seen in *Taurus*. Another Chinese chronicle makes the year 638, but neither is reconcilable with the *Nihongi*.

"5th year of Emperor Temmu, A.D. 676, autumn, 7th month. A star appeared in the East seven or eight feet in length. In the 9th month it at length disappeared from the sky."

The seventh month began August 15, and the ninth month October 13. Williams records from the Chinese annals that, A.D. 676, seventh moon, day Ting Hae = July 7, a comet was seen in *Gemini*. It was about three cubits in length. Its luminous envelope increased until it became thirty cubits in length. In the ninth moon, day Yih Yew = September 3, it disappeared. Clearly the same comet is referred to in both chronicles, and it is not improbable that the *Nihongi* account was copied from the Chinese. The discrepancy in the reduction of the date is due to Mr. Williams not having reckoned that the year 676 had an intercalary month, the first day of which was March 20.*

"10th year of Emperor Temmu, A.D. 681, 9th month, 16th day. A comet appeared."

The date is November 2. Probably taken from the Chinese, where it appeared, according to Williams, 681, ninth moon, day Ping Shin = October 17. The discrepancy is due to there being an intercalary month this year, which began August 20, and which Williams did not take into account.

"13th year of Temmu, A.D. 684, autumn, 7th month, 23rd day. A comet appeared in the north-west more than ten feet long."

* Some particulars of this comet are given by Sherburne in his work on *Manilius*, 1675. He states that it appeared in August, and lasted three months.

The 23rd day of the seventh month was September 7, there having been an intercalary month this year, the first day of which was May 20. The Chinese record, given by Williams, states: "In the epoch Wan Ming, 1st year, 7th moon, day Sin Wei, there was a comet in the West. It was about ten cubits in length. In the 8th moon, day Kea Shin, it disappeared." From this Williams gives 684 July 8 as the date when the comet was seen, and August 10 as the date of its disappearance. He further remarks that Biot makes the dates September 6 and October 9, but by computation it comes out as he has rendered it. There can be no doubt that this is Halley's Comet. The perihelion passage, according to Hind, was A.D. 684·80, which gives the date September 18.

It is impossible to reconcile Williams's dates for this comet. There can be little doubt, from the Chinese and Japanese descriptions, that the same comet is referred to. A.D. 684 was the first year of the lunar cycle, and it was embolistic. The intercalary moon began on May 20, and it followed the fourth moon of the year; consequently the seventh moon of the chronicle was actually the eighth moon of the year. I append the dates of the first day of each month in the year in question:—

1st month, 1st day	January 23
2nd " "	February 21
3rd " "	March 22
4th " "	April 20
Intercalary 4th month, 1st day ...	May 20
5th month, 1st day	June 18
6th " "	July 18
7th " "	August 16
8th " "	September 15
9th " "	October 14
10th " "	November 13
11th " "	December 12
12th " "	January 11 (685)

Meteors.

"9th year of Emperor Jomei, A.D. 637, spring, 2nd month, 23rd day. A great star floated from East to West, and there was a noise like that of thunder. The people of that day said it was the sound of the falling star."

The date is A.D. 637 March 24.

"3rd year of Emperor Tenchi, A.D. 664, 3rd month. There was a star which fell north of the capital."

The date is A.D. 664 April.

"11th year of Emperor Temmu, A.D. 682, 8th month, 3rd day. On this evening, at twilight, a great star passed from the East to the West."

The date is A.D. 682 September 10.

"13th year of Emperor Temmu, A.D. 684, 11th month, 23rd day. At sunset a star fell in the quarter of the east as large as a jar. At the hour of the Dog (*id est* 7 to 9 P.M.) the constellations were wholly disordered and stars fell like rain. During this month there was a star which shot up in the zenith and proceeded along with the *Pleiades* until the end of the month, when it disappeared."

This would seem to be a comet. The date is A.D. 685 January 3.

Aurora Borealis.

"28th year of Emperor Suiko, A.D. 620, 12th month, 1st day. There was a red appearance in the sky, over a rod in length, and resembling the tail of a fowl in shape."

Date A.D. 620 December 31.

"9th year of Emperor Temmu, A.D. 680, 11th month, 3rd day. There was a brightness in the east from the hour of the Dog to the hour of the Rat (*id est* 8 P.M. to midnight)."

Date A.D. 680 November 29. The hour of the Dog 戌 was from 7 P.M. to 9 P.M., and the hour of the Rat 子 from 11 P.M. to 1 A.M.*

* The twelve signs of the Ju-ni-shi were used to designate the twelve Chinese hours of the day, each of which consists of 120 minutes.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXVI. JANUARY 12, 1906. No. 3

W. H. MAW, Esq., PRESIDENT, in the Chair.

Lieut. George Alfred Alcock, R.N.R., R.M.S. "Athenic," c/o Shaw Savill & Albion Co., Royal Albert Dock, London, E.;
Hugh Daniel Badcock, M.A., Assoc. Mem. Inst. C.E., Town Engineer, Pretoria, Transvaal, South Africa;
Rev. Arthur Edwin Brisco-Owen, M.A., The Rectory, Cholderton, Salisbury;
William Robert Bruce, Observatorio Magnético, Pilar, Provincia de Córdoba, Argentine Republic;
Lieut. Herbert Archer Edwards, R.N.R., Marine Officer, Lagos, West Africa;
Crawford M. Fleming, 14 North Kinver Road, Sydenham, S.E.;
William Edgar Geil, M.A., F.R.G.S., Doylestown, Pennsylvania, U.S.A., and 123 Pall Mall, S.W.;
Rev. Thomas Henry Leale, A.K.C., 65 Gaskarth Road, Balham Hill, S.W.;
Lieut. Frederick William Mace, R.N.R., 2 Rutland Avenue, Sefton Park, Liverpool;
William Ottway, Orion Works; and 8 Uxbridge Road, Ealing, W.;
Legh Richmond Powell, 10 Cranfield Road, Bexhill-on-Sea, Sussex;
Rev. John Gardham Reed, Burlington Manse, South Road, Saffron Walden, Essex; and
Richard Frind Roberts, Westcroft, Warlingham, Surrey,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Frederick Joseph William Crowe, Organist of Chichester Cathedral, Marsden, Chichester (proposed by J. A. Greenwood) ;

Thomas Edward Heath, 53 Park Place, Cardiff (proposed by J. Larmor) ;

Samuel Thomas Johnson, Melrose, Bridport, Dorset (proposed by H. H. Turner) ;

George Tyrrell McCaw, B.Sc., Geodetic Survey, North Eastern Rhodesia, South Africa (proposed by S. S. Hough) ; and

Percy Alfred Talbot, B.A., F.R.G.S , F.A.I., Royal Societies' Club, St. James's Street, S.W. (proposed by E. A. Reeves).

Sixty three presents were announced as having been received since the last meeting, including, amongst others :—

T. E. Heath, Our Stellar Universe, presented by the author ; Observatoire de Bordeaux, Catalogue photographique du Ciel (coordonnées rectilignes), tome i., presented by the French Government.

Astrographic Chart of the Heavens :—18 Charts from the Royal Observatory, Greenwich ; 64 Charts from the Paris Observatory, and 10 Charts from the Observatory, San Fernando.

The Value of the Constant of Refraction. By Dr. L. de Ball.

(*Communicated by the Astronomer Royal.*)

Professor Bauschinger, in his researches on astronomical refraction,* gives the following values for the constants of refraction as reduced to the height of the barometer of 760 mm. and to the temperature of 0° C. of the internal and the external thermometer, to which I add that lately determined by Dr. Courvoisier : †

60″·120	Greenwich 1857–65	60″·209	Pulkowa 1865
·192	„ 1877–86	·058	„ 1885
·268	Tab. Pulk.	·104	Bauschinger
·122	Fuss (Pulkowa)	·161	Courvoisier

* *Annals of the Munich Observatory*, vol. iii.

† *Publications of the Heidelberg Observatory*, vol. iii.

At Greenwich and Pulkowa, however, only the reduction of the barometer to 0° C. has been applied, whereas Professor Bauschinger and Dr. Courvoisier have also taken into account the correction for gravitation and the hygrometric state of the atmosphere. A reduction has, therefore, to be applied to the above values deduced from the observations of Greenwich and Pulkowa before they can be compared with the values determined at Munich and Heidelberg. The determination of the values used for these reductions is the purpose of this paper.

For zenith distances less than 84° we can compute the refraction by means of the series

$$(1)\ \text{Refraction} = \frac{a}{\sin 1''}\left(a_0 \tan z - a_1 \tan^3 \phi z + \ldots\right)$$

where a depends on the density of the air at the place of observation, and the coefficients a_0, a_1, ... are functions of the temperature and of a. The density of the air at the place of observation can be found when we know the height of the barometer (B), the readings of the internal (τ) and external (t) thermometer, and the vapour pressure (π). In the following pages B and π are supposed to be expressed in millimeters and the temperature in centigrades. When the vapour pressure for each time of observation is not known, but only its mean value π_0, we find for the density of the air ρ (*Monthly Notices*, 1905 June)

$$(2)\ \rho = \frac{B}{760}\,\frac{1 - 0{\cdot}000162\tau}{1 + 0{\cdot}003663t}\left(1 - 0{\cdot}000000196h - 0{\cdot}00265\cos 2\phi\right)\left(1 - \tfrac{3}{8}\,\frac{\pi_0}{B}\right),$$

where h = the height of the place of observation above the sea level (in meters) and φ = the geographical latitude of the place of observation.

In order to compute the value of a, which corresponds to a given ρ, we need only know the value a_0 (the so called constant of refraction), which holds for a definite but arbitrarily chosen density ρ_0. If, namely, c is an absolute constant, then a and a_0 are determined by the equations

$$(3)\ a = \frac{c\rho}{1 + 2c\rho}, \qquad a_0 = \frac{c\rho_0}{1 + 2c\rho_0}$$

whence

$$(4)\ a = \frac{\rho}{\rho_0}\,\frac{a_0}{1 - 2a_0\left(1 - \dfrac{\rho}{\rho_0}\right)}$$

When ρ_0 = the density of the air at the place of observation for B = 760 mm., $\tau = t = 0°$ C. and vapour pressure $= \pi_0$, we have according to (2)

$$(5)\ \rho_0 = \left(1 - 0{\cdot}000000196h - 0{\cdot}00265\cos 2\phi\right)\left(1 - \tfrac{3}{8}\,\frac{\pi_0}{760}\right)$$

From (2) and (5) it follows that

$$(6)\ \frac{\rho}{\rho_0} = \frac{B(1 - 0\cdot000162\tau)}{760(1 + 0\cdot003663t)}$$

If in equation (4) we substitute this expression and the supposed known value of a_0 which corresponds to the density ρ_0 given in (5), we obtain a; by means of a and t the refraction is directly deduced from the equation (1). If, therefore, the constant of refraction corresponds to the density given in (5), we have to apply to the observed height of the barometer the reduction to 0° C. only. Reversely: *when to the observed height of the barometer we apply only the reduction to* 0° *C.* (Greenwich, Pulkowa), *and we derive from the observations the correction of an approximate value adopted for* a_0, *the new value of the constant of refraction will hold for the density of the air given in* (5).

If besides the height of the barometer and the temperature we also know the observed vapour pressure π, we obtain instead of the approximate value (2) of ρ its exact value when we substitute π for π_0; therefore we have

$$(7)\ \rho = \frac{B}{760}\,\frac{1 - 0\cdot000162\tau}{1 + 0\cdot003663t}(1 - 0\cdot000000196h - 0\cdot00265\cos 2\phi)\left(1 - \tfrac{3}{8}\frac{\pi}{B}\right)$$

Choosing for ρ_0 the density of the air at the sea level and at the geographical latitude of 45° for B = 760 mm., $\tau = t =$ 0°C., $\pi =$ 6 mm., we obtain

$$(8)\ \rho_0 = 1 - \tfrac{3}{8}\,\tfrac{6}{760}$$

and from (7) and (8) when, for brevity, we put

$$(9)\ B\left\{1 - 0\cdot000162\tau - 0\cdot000000196h - 0\cdot00265\cos 2\phi + \tfrac{3}{8}\left(\tfrac{6}{760} - \frac{\pi}{B}\right)\right\} = b,$$

it follows that

$$(10)\ \frac{\rho}{\rho_0} = \frac{b}{760(1 + 0\cdot003663t)}$$

Here we may repeat—*mutatis mutandis*—the remarks made above in connection with the equation (6), and it appears that: *If instead of the observed height of the barometer B we use the barometer height b, as reduced according to the equation* (9) [Bauschinger, Courvoisier], *the value of the constant of refraction deduced from the observations holds for the density of the air given in* (8).

In order to reduce the values of the constants of refraction, determined in Greenwich and in Pulkowa, to that density of the air for which the values of Professor Bauschinger and Dr. Courvoisier hold we must put in the equation (4), instead of ρ, the

value given in (8), and, instead of ρ_0, that given in (5). We then obtain

$$(11)\quad \alpha-\alpha_0=\alpha_0\left(0{\cdot}000000196h+0{\cdot}00265\cos 2\phi+\tfrac{3}{8}\frac{\pi_0-6}{760}\right)$$

We have for

Greenwich	$\alpha_0 = 60''{\cdot}156$ (mean),	$h = 47^m$,	$2\phi = 102^\circ\ 57'$
Pulkowa	„ $= 60{\cdot}164$ „	„ $= 75$,	„ $= 119\ 33$

Hence, if first we neglect the member depending on π_0,

Greenwich	$\alpha-\alpha_0 = -0''{\cdot}035$
Pulkowa	„ $= -0{\cdot}078$

Therefore we obtain for *the value of the constant of refraction reduced to the density* $\rho_0 = 1-\frac{3}{8}\frac{6}{760}$, *and hence to* $h=0$, $\phi=45^\circ$, $B=760$ mm., $\tau=t=0^\circ$ C., $\pi=6$ mm.

Greenwich	$60''{\cdot}121+0''{\cdot}030(\pi_0-6)$
Pulkowa	$60{\cdot}086+0{\cdot}030(\pi_0-6)$
Munich	$60{\cdot}104$
Heidelberg	$60{\cdot}161$

If the observations were equally distributed over the whole year we might accept for π_0 the mean from the monthly means of the vapour pressure of Greenwich and Pulkowa respectively, but this assumption on the distribution of the observations is not permissible. However, even if π_0 were known, the correction depending on π_0 would be uncertain, for it is possible that in the expression for the correction mentioned $\frac{1}{8}$ has to be put in the place of $\frac{3}{8}$ (*Monthly Notices*, 1905 June).

Vienna-Ottakring: 1905 *November* 13.

Note on an Experiment on Lateral Refraction.
By B. F. E. Keeling, Survey Department, Egypt.

(*Communicated by Professor H. H. Turner.*)

A geodetic triangulation is about to be made by the Egyptian Survey Department with the object of linking up the South African survey along the 30° E. meridian and the Russian triangulation. The first question which was raised was the position of the chain, whether to utilise in the main the Nile Valley or to take the chain wholly to east or west of it. From the point of view of convenience and economy the former is evidently to be preferred, but it was asked whether it would not

militate against accuracy to have a large number of sights with their end sections over the desert and the middle sections over the cultivated Nile Valley. It was feared that there might be considerable differences in the apparent lines of sight between day and night, and it was with the object of testing the stability of the apparent line joining two stations that this experiment was undertaken.

The experiment was on the lines of that by C. M. v. Bauernfeind,* but instead of four only two signals were observed. The theodolite used was a 40-centimetre one made by Brünner in (about) 1860, and readjusted recently by Cooke & Sons. It has an object-glass 60 mm. in diameter and of about 750 mm. focal length. The eyepiece micrometer reads directly to seconds. The theodolite was mounted on a brick pier isolated from the floor in one of the buildings of Helwan Observatory, about 100 metres above the Nile. The first signal was about 600 metres distant, and consisted of a metal plate mounted in a brick wall. In the plate was a hole one centimetre in diameter which was illuminated from behind by a heliograph during the day and a bicycle lamp at night. Between the theodolite and this mark was a small ravine 10 to 30 metres deep. The distant station was situated on the other side of the Nile Valley on a low hill near the pyramids of Giza, and was also some 100 metres above the Nile. It was about 25 kilometres from the theodolite.

A 5-in. heliograph was used by day and a powerful motor lamp at night, both being self-centring on a brass support cemented into a brick pillar.

The line of sight crossed about 7 kilometres of desert at each end with 11 kilometres of cultivation in the middle. The two signals were nearly in the same straight line as seen from the theodolite, the angle between them being about 10′. The measures were made entirely with the eyepiece micrometer, the two signals being successively brought into the field of view by the slow motion of the vertical circle.

Two series of observations were made. The first was spread over five days in April 1905. The work was a good deal interrupted by a sand storm which was blowing for a great part of the time. The maximum and minimum temperatures are given for each day, and it will be seen that the range was large and the temperatures high.

The second series was made in December 1905. The weather was for the most part clear, with mists which interrupted the observations in the early morning. Both the temperatures and the daily range were very much lower than in the former experiment, whilst the humidity was higher. The effective width of cultivation was greater, as the flood-water had only just been drawn off the land, and the whole of the 11 kilometres was wet.

* *Ergebnisse aus Beobachtungen der terrestrischen Refraktion.* München, Akad. Abhandl., xiii., 1880.

The tables which follow give the results of the observations. No accurate determination of the value of the micrometer was made in either case, so the two series are not comparable with each other as regards absolute values.

The calculated error of a single observation considered by itself was from ±0·1 to ±0·3 of a division.

It does not appear that there is any regular diurnal swing of the line of sight, and indeed the divergence of any observation from the mean is so little greater than the calculated probable error of the observation that the experiments, so far as they go, show that if observations are spread over a few days the Nile Valley will not be unfavourable to triangulation. The line of sight was intentionally lower than will usually be the case in the actual triangulation.

Incidentally some information can be gleaned as to the hours of work available, though of course the number of days over which the work extended was small. The light from the heliograph was always in vibration; its apparent diameter was often as much as 60 in., and often numerous sparks were shot off in all directions. But still the observations seem to show that it is only rarely that work need be discontinued, and, moreover, that the morning observations and condition of the atmosphere were not greatly inferior to those in the evening.

TABLE I.

Date.	Time.	Observed Angle 3t+divs.	Mean−Observed E.	Temp. ° C.	Relative Humidity. %	—	Temp. Max. ° C.	Temp. Min. ° C.	Humidity %. 8 am.
18 4 05	7 p.m.	19·6	−0·4	30	4		...	...	...
	9 p.m.	19·5	−0·5	26	10	Helwan	37	14	49
	11 p.m.	20·2	+0·2	25	8	Giza *	36	11	60
19 4 05	6 a.m.	20·6	+0·6	20	16				
	7 a.m.	20·8	+0·8	25	14				
	7 p.m.	20·5	+0·5	36	4	Helwan	39	18	21
	9 p.m.	20·5	+0·5	26	31	Giza *	39	14	53
20 4 05	1 a.m.	19·4	−0·6	20	40				
	7 a.m.	21·0	+1·0	24	13				
	9 a.m.	19·4	−0·6	27	33	Helwan	41	16	35
	11 a.m.	20·4	+0·4	35	9	Giza *	36	15	65
21 4 05	7 p.m.	19·5	−0·5	37	11				
	9 p.m.	19·5	−0·5	33	10	Helwan	42	21	24
	11 p.m.	19·2	−0·8	33	7	Giza *	41	14	56
22 4 05	3 a.m.	19·7	−0·3	29	8				
	5 a.m.	19·9	−0·1	27	11				
	7 a.m.	20·4	+0·4	27	14	Helwan	42	26	6
	9 a.m.	20·3	+0·3	34	7	Giza *	41	24	21
	7 p.m.	20·5	+0·5	37	7				
	9 p.m.	19·6	−0·4	20	15				
	Mean	20·02							

1 div. = 1 sec. nearly.

* Meteorological station in the cultivation.

TABLE II.

Date.	Time.	Observed Angle 3t+divs.	Mean—Observed Divs.	Temp. o° C.	Relative Humidity. %	—	Temp. Max. ° C.	Temp. Min. ° C.	Humidity %. 8 a.m.
4 12 05	10 a.m.	19·7	−0·7	18	38				
	2 p.m.	20·9	+0·5	21	35				
	6 p.m.	20·0	−0·4	17	38	Helwan	22	10	63
	8 p.m.	20·0	−0·4	15	54	Giza	24	8	79
	Midn.	19·9	−0·5	12	46				
5 12 05	2 a.m.	20·2	−0·2	12	51				
	10 a.m.	20·4	±0·0	16	46				
	Noon	20·7	+0·3	20	36				
	2 p.m.	20·8	+0·4	21	32	Helwan	22	10	51
	4 p.m.	20·4	±0·0	21	25	Giza	25	8	66
	6 p.m.	21·0	+0·6	18	43				
	8 p.m.	20·9	+0·5	16	46				
6 12 05	8 a.m.	20·6	+0·2	12	59				
	10 a.m.	20·5	+0·1	17	50				
	Noon	21·6	+1·2	19	42				
	2 p.m.	20·8	+0·4	22	36	Helwan	22	9	58
	4 p.m.	20·4	±0·0	21	42	Giza	23	9	69
	6 p.m.	19·5	−0·9	19	54				
	10 p.m.	20·6	+0·2	16	68				
7 12 05	10 a.m.	21·1	+0·7	20	59				
	Noon	20·6	+0·2	22	42				
	2 p.m.	20·6	+0·2	23	39				
	4 p.m.	19·4	−1·0	22	43	Helwan	24	14	76
	6 p.m.	20·6	+0·2	20	48	Giza	26	9	100
	8 p.m.	20·8	+0·4	18	59				
	Midn.	20·7	+0·3	17	72				
8 12 05	10 a.m.	19·8	−0·6	20	61				
	Noon	20·1	−0·3	23	43				
	2 p.m.	19·8	−0·6	23	40	Helwan	23	14	74
	4 p.m.	20·5	+0·1	22	50	Giza	24	11	88
	8 p.m.	20·6	+0·2	18	72				
	Mean	20·4							

1 div. = 1 sec. nearly.

I have to tender my best thanks to Captain H. G. Lyons, R.E., Director-General of the Survey Department, for providing facilities for this work and sanctioning its publication.

Note on the Motion about an Attracting Centre of slowly increasing Mass. By H. C. Plummer, M.A.

1. The dynamical problem of motion under the attraction of a body of increasing mass was suggested by Oppolzer * in an attempt to explain a part of the secular acceleration of the Moon as a result of the deposition of meteoric matter on the Earth. It has since been discussed by Gyldén,† Mestschersky,‡ Lehmann-Filhés,§ and E. Strömgren.‖

The same theory is recalled by Mr. Cowell's conclusion that the motion of the Earth round the Sun is also affected by a secular acceleration. It is true that the idea that this can be attributed to a gradual increase in the mass of the Sun is not borne out by Mr. Cowell's result for the motion of *Mercury*; but this consideration may not be quite decisive, since the motion of this planet is known to be incompletely explained by theory. However this may be, the effect of an increase in the central body is a point of some interest, and a short discussion is here given of the simplest case, that in which the rate of increase is constant.

2. Let $\mu u^2(1+at)$ represent the law of central attraction, u being the reciprocal of the radius vector. Since the force is central, the integral of areas holds, and the equations of motion may be written

$$r^2\frac{d\theta}{dt}=h \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$\frac{d^2u}{d\theta^2}+u=\frac{\mu}{h^2}(1+at) \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Now if powers of a above the first be neglected, it is easily verified that these equations are satisfied by the solution

$$u=\frac{\mu}{h^2}\{1+e\cos(\theta-\gamma)\}(1+at) \quad \ldots \quad \ldots \quad (3)$$

where

$$u=\frac{\mu}{h^2}\{1+e\cos(\theta-\gamma)\} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

can be regarded as the undisturbed (though not the osculating) orbit at the time $t=0$. Let R and T be the radius vector and time in this undisturbed orbit corresponding to the anomaly θ. Then in the disturbed orbit

$$r=\mathrm{R}/(1+at)$$

and

$$\int \mathrm{R}^2 d\theta = h\int(1+at)^2\,dt$$

or

$$\mathrm{T}=t(1+at)$$

* *A. N.*, 2573. † *A. N.*, 2593. ‡ *A. N.*, 3153, 3807.
§ *A. N.*, 3480. ‖ *A. N.*, 3897.

Hence at any time the deviations of the disturbed from the undisturbed orbit for the same anomaly θ are given by

$$\frac{\Delta r}{r} = \frac{\Delta t}{t} = -at \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

and the increase in the anomaly in a given time t is

$$-\frac{d\theta}{dt}\Delta t = ahr^{-2}t^2 \ldots \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

3. The required results are thus obtained more simply and directly than by the variation of elements; but the first-order variations of e, γ and a can be deduced very easily. In the equation (3) of the actual trajectory, t is to be regarded as a function of θ; the osculating orbit at the point θ is

$$u = \frac{\mu}{h^2}\{1 + e' \cos(\theta - \gamma')\}(1 + at) \quad \ldots \quad \ldots \quad (7)$$

where t is to be regarded as constant. The identity of the radius and tangent in the two curves gives

$$e' \cos(\theta - \gamma') = e \cos(\theta - \gamma)$$
$$e' \sin(\theta - \gamma') = e \sin(\theta - \gamma) - ahr/\mu$$

which lead to

$$\Delta(e \cos\gamma) = -ahr \sin\theta/\mu$$
$$\Delta(e \sin\gamma) = \quad ahr \cos\theta/\mu$$

or finally to

$$\Delta e = -\frac{ah}{\mu} r \sin(\theta - \gamma) = -a \cdot \frac{h^3}{\mu^2} \cdot \frac{\sin E}{(1 - e^2)^{\frac{1}{2}}} \quad \ldots \quad (8)$$

$$\Delta\gamma = \frac{ah}{e\mu} r \cos(\theta - \gamma) = a \cdot \frac{h^3}{\mu^2} \cdot \frac{\cos E - e}{e(1 - e^2)} \quad \ldots \quad (9)$$

where E is the eccentric anomaly corresponding to θ.

The mean distance in the osculating orbit is

$$a' = \frac{h^2}{\mu(1 - e'^2)(1 + at)}$$

Hence

$$\Delta a = a\left(-at + \frac{2e\Delta e}{1 - e^2}\right)$$

$$= -aa\left\{t + \frac{2h^3}{\mu^2} \cdot \frac{e \sin E}{(1 - e^2)^{\frac{1}{2}}}\right\} \quad \ldots \quad \ldots \quad (10)$$

Equations (8), (9) and (10) may be compared with equations (25) of Dr. Strömgren's paper; the two sets differ by additive constants which can be introduced into the above to annul the variations at a given epoch, as $t = 0$. The variations found above are referred to the intermediate orbit whose equation is (4).

University Observatory, Oxford:
1906 *January* 10.

Mean Areas and Heliographic Latitudes of Sun-spots in the Year 1904, *deduced from Photographs taken at the Royal Observatory, Greenwich; at Dehra Dûn; at Kodaikánal Observatory, India; and in Mauritius.*

(*Communicated by the Astronomer Royal.*)

The results here given are in continuation of those printed in the *Monthly Notices*, vol. lxv. p. 151, and are deduced from the measurements of photographs taken at the Royal Observatory, Greenwich; at Dehra Dûn; at the Kodaikánal Observatory, India; and at the Royal Alfred Observatory, Mauritius.

Table I. gives the mean daily area of umbræ, whole spots, and faculæ for each synodic rotation of the Sun in 1904; and Table II. gives the same particulars for the entire year 1904 and the three preceding years for the sake of comparison. The areas are given in two forms: first, projected areas; that is to say, as seen and measured on the photographs, these being expressed as millionths of the Sun's apparent disc; and next areas as corrected for foreshortening, the areas in this case being expressed in millionths of the Sun's visible hemisphere.

Table III. exhibits for each rotation in 1904 the mean daily area of the whole spots (corrected for foreshortening) and the mean heliographic latitude of the spotted area for spots north and for spots south of the equator, together with the mean heliographic latitude of the entire spotted area and the mean distance from the equator of all spots; and Table IV. gives the same information for the year as a whole, similar results for the three preceding years being added, as in the case of Table II.

Tables II. and IV. are thus in continuation of the similar tables for the years 1874 to 1888 on pp. 381 and 382 of vol. xlix. of the *Monthly Notices*, and for the years 1889 to 1902 on pp. 465 and 466 of vol. lxiii., and for the years 1901 to 1903 on pp. 152 and 153 of vol. lxv.

The rotations in Table I. and Table III. are numbered in continuation of Carrington's series (*Observations of Solar Spots made at Redhill*, by R. C. Carrington, F.R.S.), No. 1 being the rotation commencing 1853 November 9. The assumed prime meridian is that which passed through the ascending node at mean noon of 1854 January 1, and the assumed period of the Sun's sidereal rotation is 25·38 days. The dates of the commencement of the rotations are given in Greenwich civil time, reckoning from mean midnight.

The principal features of the record for 1904 are:

1. The comparatively slow, though steady, increase in the mean daily spotted area, the umbræ showing an advance on 1903 of only 32 per cent.; the whole spots of 44 per cent. The years in the two preceding cycles showing this relation to the years which they followed were 1882 and 1893, when the actual maximum was very close at hand.

TABLE I.

No. of Rotation.	Date of Commencement of each Rotation.		No. of Days on which Photographs were taken.	Mean of Daily Areas. Projected. Umbræ.	Projected. Whole Spots.	Projected. Faculæ.	Corrected for Foreshortening. Umbræ.	Corrected. Whole Spots.	Corrected. Faculæ.
	1903.	d							
672	Dec.	20·64	26	57	353	1164	46	287	1338
	1904.								
673	Jan.	16·98	27	93	638	883	65	456	1000
674	Feb.	13·32	26	61	401	899	45	296	1015
675	Mar.	11·65	27	75	483	1413	52	347	1532
676	Apr.	7·94	28	209	1398	1547	143	1018	1658
677	May	5·20	26	42	298	1914	30	217	2059
678	June	1·41	28	61	495	1580	41	339	1628
679		28·61	27	91	715	1928	65	525	1966
680	July	25·82	27	67	516	2005	48	385	2100
681	Aug.	22·05	27	71	608	1697	50	454	1805
682	Sept.	18·30	28	101	713	1858	72	520	1933
683	Oct.	15·59	27	93	633	1719	73	506	1888
684	Nov.	11·89	27	103	638	1714	89	592	1969
685	Dec.	9·20	26	149	1054	2600	106	750	2813

TABLE II.

Year.	No. of Days on which Photographs were taken.	Mean of Daily Areas. Projected. Umbræ.	Projected. Whole Spots.	Projected. Faculæ.	Corrected for Foreshortening. Umbræ.	Corrected. Whole Spots.	Corrected. Faculæ.
1901	359	14	41	23	86	29	29
1902	349	14	86	163	10	62	178
1903	350	67	434	870	51	339	969
1904	363	93	653	1639	67	488	1761

TABLE III.

No. of Rotation.	Date of Commencement of each Rotation.		No. of Days on which Photographs were taken.	Spots north of the Equator. Mean of Daily Areas.	Spots north. Mean Heliographic Latitude.	Spots south of the Equator. Mean of Daily Areas.	Spots south. Mean Heliographic Latitude.	Mean Heliographic Latitude of Entire Spotted Area.	Mean Distance from Equator of all Spots.
	1903.	d			°		°	°	°
672	Dec.	20·64	26	163	18·70	124	16·59	+ 3·40	17·78
	1904.								
673	Jan.	16·98	27	312	16·82	144	14·70	+ 6·87	16·20
674	Feb.	13·32	26	68	15·73	229	13·82	− 7·08	14·25
675	Mar.	11·65	27	276	13·63	72	17·39	+ 7·23	14·40
676	Apr.	7·94	28	302	14·58	717	14·49	− 5·88	14·52
677	May	5·20	26	72	17·13	145	20·09	− 7·78	19·11
678	June	1·41	28	267	16·03	72	18·82	+ 8·62	16·63
679	June	28·61	27	254	15·05	272	18·97	− 2·52	17·05
680	July	25·82	27	200	15·45	185	16·49	+ 0·10	15·95
681	Aug.	22·05	27	54	18·77	400	17·62	−13·28	17·76
682	Sept.	18·30	28	271	18·95	249	19·81	+ 0·39	19·36
683	Oct.	15·59	27	300	12·26	206	18·34	− 0·15	14·73
684	Nov.	11·89	27	477	19·06	115	19·98	+11·50	19·24
685	Dec.	9·20	26	629	17·04	121	16·44	+11·65	16·95

TABLE IV.

Year.	No. of Days on which Photographs were taken.	Spots north of the Equator. Mean of Daily Areas.	Mean Heliographic Latitude.	Spots south of the Equator. Mean of Daily Areas.	Mean Heliographic Latitude.	Mean Heliographic Latitude of Entire Spotted Area.	Mean Distance from Equator of all Spots.
1901	359	22	$8^\circ.59$	6·6	$16^\circ.27$	$+2^\circ.82$	$10^\circ.37$
1902	349	42	18·81	21	15·29	+7·48	17·64
1903	350	133	18·12	206	21·10	−5·75	19·93
1904	363	268	16·33	220	16·88	+1·37	16·57

2. Not only has the general increase of activity in 1904 been slight, but no single rotation of the year has equalled either the 11th or 12th rotations of 1903 in spotted area, and only one—that beginning 1904 April 7, No. 676—has approached them. For the rest of the year the spot activity has been fairly evenly distributed, with a tendency to increase as the year went on.

3. The faculæ have shown a much more marked increase than the spots, the advance on 1903 being 82 per cent. The progress has gone on steadily throughout the year, the last rotation showing much the greatest area for the faculæ.

4. Comparing the whole spots of the two hemispheres, the area for the northern has been to that of the southern as 55 to 45. This is a return to the precedent of the two preceding cycles, in so far that the northern hemisphere showed a superiority over the southern during the years of chief increase of the solar activity in those two cycles; but is a departure from their precedent in that the balance had swung over to the southern side by the time that the amount of increase had become as small as 44 per cent. The near approach to equality between the two hemispheres would mean, according to the precedent of the last two cycles, that the maximum had not yet been reached, but might be expected in 1905 or early in 1906.

5. Neither hemisphere has been undisturbed for a complete rotation at any time during 1904.

6. Nor was there a single day without spots in the year. This is in sharp contrast to 56 such days in 1903, 248 in 1902, and 289 in 1901.

7. The distribution of spots in latitude in each hemisphere, equally with their distribution between the two hemispheres, appears to point to the near approach of the maximum. The chief spot activity has lain between 24° and 10° in both hemispheres, but has not been restricted to it, for there has been occasional action over the entire zones 33° to 6°, and one or two instances of sporadic spots outside even these wide limits have been noticed. Thus on 1904 November 28 a spot was seen in N. lat. 41°, and on November 29 another in N. lat. 38°; whilst an equatorial group was observed on 1904 January 1. The

appearance of spots over so wide a range of latitude is usually an indication that the maximum is close at hand.

8. The comparison of the mean distance from the equator of all spots for 1904 with the corresponding years of the two preceding cycles is interesting, and marks the present cycle as decidedly unlike the two preceding cycles in its progress. The centre of gravity of the spot-zone has already approached considerably nearer to the equator than in the year before maximum of those two cycles, but the area attained is much smaller. The area in fact is that of nearly three years before maximum, but the mean distance from the equator approaches that of the year of maximum, as the following little table will show:

TABLE V.

Cycle.	Date of Maximum.	Year.	Mean Distance from Equator of all Spots.	Mean Daily Area of Whole Spots.
1879–1889	1883·9	1880	19°·80	416
		1881	18·21	730
		1882	17·81	1002
		1883	13·04	1155
1890–1901	1893·9	1890	21·99	99
		1891	20·31	569
		1892	18·39	1214
		1893	14·49	1464
1902– ...	...	1904	16·57	488

9. The number of separate groups of spots was 84 per cent. greater than in 1903, so that the average size of the groups was not quite as great as in the earlier year. There was no single group at all comparable in area with the great group of 1903 October 4–17. In all, the groups of 1904 were 276 in number, 165 being in the northern hemisphere and 111 in the southern.

Royal Observatory, Greenwich:
1906 January 8.

Observation of Comet b 1904 (Encke) from a Photograph taken with the 30-inch Reflector of the Thompson Equatorial at the Royal Observatory, Greenwich.

(Communicated by the Astronomer Royal.)

Date and G.M.T. 1904	Apparent R.A.	Apparent Dec.	Log. Δ.	Corr. for Parallax R.A.	Corr. for Parallax Dec.
d h m s	h m s	° ′ ″		s	″
Dec. 7 6 42 19	20 50 20·95	+5 51 24·6	9·6830	+·53	+13·3

Royal Observatory, Greenwich:
1906 January 5.

Observations of Comet b 1905 from Photographs taken with the 30-inch Reflector of the Thompson Equatorial at the Royal Observatory, Greenwich.

(*Communicated by the Astronomer Royal.*)

The following positions of Comet *b* 1905 were obtained from photographs taken with the 30-inch reflector. As a rule these were four images on each plate with exposures of from 1^m to 2^m. The plates were measured in the astrographic micrometer. Four reference stars were taken in each case, situated as symmetrically as possible about the comet. The positions of the reference stars were derived from the Catalogues of the Astronomische Gesellschaft.

Date and G.M.T. 1905 d h m s	Apparent R.A. h m s	Apparent Dec. ° ′ ″	Log. Δ.	Corr. for Parallax R.A. s	Corr. for Parallax Dec. ″
Nov. 20 10 9 41	23 54 39·31	62 8 28·7	9·3825	+1·77	− 3·6
21 8 13 25	23 47 2·78	54 1 25·5	9·3912	+ ·30	− 1·6
23 9 55 53	23 38 18·44	37 31 24·9	9·4346	+1·01	+10·1
24 6 38 12	23 36 18·09	31 43 40·3	9·4649	− ·29	+10·3
27 6 13 18	23 32 21·40	16 35 6·6	9·5657	− ·25	+13·7
29 6 27 34	23 31 6·11	9 43 1·8	9·6312	− ·12	+10·8

Further details of the observations will be given in the Greenwich volume.

Royal Observatory, Greenwich:
1906 *January* 5.

Observations of Mösting A made with the Altazimuth and Transit Circle at the Royal Observatory, Greenwich.

(*Communicated by the Astronomer Royal.*)

From the beginning of 1905, in concert with the Cape Observatory, observations of Mösting A have been made on the meridian when the Moon was in the second or third quarter. The primary object is a determination of the parallax of the Moon from the observations of N.P.D., the culminators being also observed at both observations for the elimination of the instrumental errors.

At Greenwich the limbs have as far as possible been observed as well as the crater, as in this way the observations of 1L are connected with those of 2L, and those of NL with SL.

The following table gives the tabular errors of the Moon's

centre in right ascension from the Greenwich meridian observations with the altazimuth and transit circle. Those in N.P.D. cannot be given at present, as the corrections for R—D discordance for the two instruments have not yet been determined. The observations in N.P.D. of the limbs and crater with the same instrument can, however, be compared, as they are equally affected by the R—D corrections.

Apparent Error of the Tabular Right Ascensions of the Moon's Centre, from Observations of Mösting A and of the Moon's Limbs.

Date.	Mösting A Altaz.	Mösting A T.C.	Limb. Altaz.	Limb. T.C.	Limb Obsd.	Date.	Mösting A Altaz.	Mösting A T.C.	Limb. Altaz.	Limb. T.C.	Lim Obs
	s		s	s			s		s	s	
Jan. 14	−0·33	...	−0·37	−0·33	1	June 19	−0·21	...	−0·29	−0·14	2
25	−·09	...	−·17	−·08	2	20	−·22	...	−·19	−·20	2
27	−·18	...	−·25	−·13	2	22	−·22	...	−·05	−·11	2
Feb. 17	−·62	...	−·60	−·58	1	July 13	...	−0·59	...	−·43	1
20	−·32	...	...	−·29	2	15	...	−·44	...	−·41	1
Mar. 14	−·41	...	−·52	−·50	1	20	...	−·15	...	−·08	2
15	−·66	...	−·62	−·67	1	21	−·31	...	−·25	−·04	2
17	−·74	...	−·74	−·63	1	Aug. 11	...	−·40	...	−·46	1
18	−·70	−·72	−·67	−·74	1	16	...	−·22	...	−·19	2
19	−·62	−·59	−·52	−·54	1	Sept. 7	−·32	−·16	−·26	−·20	1
21	−·56	−·64	−·40	−·43	2	8	−·35	−·22	−·32	−·45	1
22	−·36	...	−·20	−·27	2	12	−·22	−·07	−·18	−·19	1
25	−·27	...	−·20	+·02	2	18	−·35	...	−·23	−·19	2
Apr. 14	−·73	...	−·68	−·75	1	19	−·33	−·19	−·33	−·38	2
18	−·58	...	−·54	−·55	1	20	...	−·39	−·48	−·55	2
22	−·37	−·16	−·34	−·17	2	Oct. 7	−·32	...	−·26	−·28	1
23	−·26	...	−·20	−·23	2	10	−·19	−·25	−·01	−·23	1
May 15	−·58	...	−·57	−·57	1	13	...	...	−·18	−·21	2
17	−·51	−·44	−·47	−·48	1	16	−·37	−·44	−·33	−·29	2
21	−·18	...	−·19	...	2	19	−·45	...	−·42	−·45	2
22	−·14	...	−·31	+·01	2	Nov. 6	−·24	−·21	−·24	−·16	1
23	−·16	...	−·07	−·11	2	7	−·23	−·13	−·20	−·20	1
June 14	−·59	...	−·40	−·37	1	Dec. 8	...	−·38	−·18	−·28	1
18	−·35	...	−·31	−·22	2	9	−·24	−·33	−·29	−·43	1

The most striking features in the above are (1) the close agreement of the observations made with the two instruments and by the two methods of observing; and (2) the large amount of the Moon's error in right ascension, amounting to nearly $-0^{\mathrm{s}}\cdot 40$ in the mean for the year. This value is confirmed by the observations of limbs in the first and last quarters with the transit circle and by the extra-meridian observations with the altazimuth.

The following table gives the difference of R.A. or N.P.D. of the centre as determined from observations of the crater or a limb when both were observed with the same instrument. The differences of R.A. can be found from the table given above.

	Differences of R.A. of Moon's Centre.				Differences of N.P.D. of Moon's Centre.			
	Altazimuth.		Transit Circle.		Altazimuth.		Transit Circle.	
	Möst. A. −1L	Möst. A. −2L	Möst. A. −1L	Möst. A. −2L	Möst. A. −NL	Möst. A. −SL	Möst. A. −NL	Möst. A. −SL
	s	s	s	s	″	″	″	″
	−·04	−·08	−·02	+·21	+0·94	−0·34	−0·59	−1·94
	+·02	−·07	+·05	−·01	+0·31	+0·21	+2·49	−0·67
	−·11	+·16	−·04	+·07	−2·72	+0·36	+1·10	+1·89
	+·04	+·16	+·16	+·03	+3·24	−3·57	−2·32	+3·37
	·00	+·07	+·03	−·19	−0·34	+0·21	−1·33	+0·11
	+·03	+·03	−·06	−·16	−2·97	+1·76	+0·11	+1·62
	+·10	+·06	−·04	+·15	−0·77	+0·11	+0·34	+2·62
	+·05	−·01	−·23	...	−1·61	+0·81	−0·39	+0·53
	+·04	−·17	−·12	...	+2·54	+0·66	−1·50	+1·13
	+·01	+·09	+·02	...	−0·09	+0·70	+0·22	...
	+·04	+·04	+·05	...	−1·14	+0·93	+1·25	...
	+·19	−·08	−·07	...	+1·02	−0·43	+0·14	...
	+·06	+·03	+·10	...	−0·18	...	...	...
	+·03	+·17	+·10	...	−1·60	...	...	...
	+·04	+·06	...	...	...	...	...	...
	+·06	+·12	...	...	...	...	...	...
	+·18	·00	...	...	...	...	...	...
	·00	+·04	...	...	...	...	...	...
	+·03	+·03	...	...	...	...	...	...
	−·05	...	...	...	...	...	...	...
Mean	+·036	+·033	−·019	·014	−0·24	−0·02	−0·04	+0·96

The differences of right ascension of Mösting A given by the two instruments are as follows:—

Altazimuth − Transit Circle.

s	s	s
−·02	+·16	−·07
+·03	+·13	+·03
−·08	+·14	+·10
+·21	+·14	−·09
+·07	−·06	
Mean	+ˢ·05	

The observations are not sufficient for much weight to be attached to these results, but it seems desirable to draw atten-

tion to them in view of the questions attaching to the observations of limbs.

As showing the amount of accidental error in observations of the Moon, the following comparison of altazimuth observations of Mösting A with transit-circle observations of the limbs has been made in R.A. As these are essentially different observations with different instruments, this comparison will give reliable values of the accidental errors.

Excess of Right Ascension of the Moon's Centre as obtained from Altazimuth Observations of Mösting A over Transit Circle Observations of the Moon's Limbs.

s	s	s	s
·00	+·13	+·05	+·16
+·01	+·09	+·22	−·05
+·05	+·29	+·13	+·04
+·04	−·02	+·07	−·04
+·03	+·03	+·02	+·08
−·09	+·20	+·11	·00
−·01	+·03	+·27	+·08
+·11	+·01	+·12	+·03
−·04	+·03	−·10	−·19
+·08	+·15	+·03	...

The algebraic mean of these quantities is $+^s\cdot055$, and the arithmetic mean $\pm^s\cdot083$ or $\pm^s\cdot072$ when the mean $+^s\cdot055$ is taken out. If the observations of Mösting A with the altazimuth and of the limb with the transit circle be taken as equally accurate, the probable error of an observation is $\pm^s\cdot052$, or $\pm^s\cdot044$, according as the uncorrected or corrected value of the arithmetic mean is taken.

Royal Observatory, Greenwich:
1906 *January* 11.

Lunar Nomenclature. By Walter Goodacre.

I think it will be readily granted by those who take an interest in lunar topography that the publication of Mr. S. A. Saunder's catalogue of 1433 measured points on the Moon's surface marks an epoch in selenography.

The completion of a task of this magnitude and importance could not fail to bring up once more the question of lunar nomenclature. The chaotic condition of this subject which at present exists and the urgent need for reform have been fully illustrated and set forth in the paper read by Mr. Saunder at the last meeting of the Society.

It now remains to be seen if it is not possible that some method can be devised by which the matter may be placed on some final and comprehensive basis.

Without going over the ground already covered by Mr. Saunder, it is sufficient to say that the nomenclature of Riccioli in the main was adopted by Beer and Mädler, and it has become the standard recognised by all subsequent selenographers, though all have made additions or alterations to it as they thought fit.

The real difficulty in lunar nomenclature is found to arise when we seek to formulate a system for marking and cataloguing the minor details which abound on the Moon's surface.

One great step towards the solution of this difficulty could be taken by dividing the Moon's surface into districts or provinces analogous to English counties, each of which would be associated as far as possible with some well-marked object already named as a centre.

This plan was proposed to the late W. R. Birt, F.R.A.S., by the late Rev. Dr. Richards, and was published in the *E.M.*, 1878 April 19. Mr. Birt expressed his approval of the scheme, and it was adopted, I believe, to some extent by the Council of the Selenographical Society. Had the plan been put to the test practical difficulties almost insurmountable would have been encountered, arising principally from the fact that whilst lunar charts, such as those of Neison and Schmidt, were then in existence, and could easily have been divided into conveniently sized districts, the boundary lines must of necessity have been of a purely arbitrary nature and liable to constant alteration, because in practice they would have been found in most cases out of harmony with the natural boundaries, as revealed in the telescope.

The numerous and excellent lunar photographs now in existence, and in which the true configuration of the surface in every part can be seen under suitable angles of illumination, will afford a ready means of tracing natural boundaries between the various objects, and thus rendering the task, which was impossible before, easy of accomplishment.

Having got our boundaries thus fixed, the question now arises as to the manner in which we are to mark and catalogue the various objects within these limited spaces, and it is upon this point that so many opinions are likely to arise, and from the discussion of which it may be hoped a generally accepted system may result.

It is purely with the object of eliciting the views of others that I venture to explain my own on this matter.

The publication of Mr. Saunder's catalogue, already referred to, makes some settlement of this question one of urgency.

In support of this statement I may mention one fact which, I think, amply bears it out.

In glancing down the columns in this catalogue it will be

seen that a number of objects whose positions he has measured are entered without a name or even a letter or number, showing that they are not marked in any way (if shown) on the various maps he has consulted. (A hurried count of these anonymous objects makes their number to be no less than 841 out of 1433.) In many cases there is no agreement between the maps in the lettering of minor objects, which renders it impossible to draw up a correct catalogue.

The want of a suitable method of lunar nomenclature was recognised by the Lunar Committee appointed more than thirty years ago by the British Association, when Mr. Birt and his colleagues drew up an entirely new system, which was as follows:

The Moon's surface was divided into the usual four quadrants —N.W., N.E., S.E., and S.W.—and numbered I. to IV., using Roman figures.

Each of these quadrants was again divided into sixteen grand divisions, distinguished by capital letters from A to Q, and consisting of an area of 25° square, except towards the limb, where of necessity only 15° remain on this hemisphere, and the remaining 10° extend into the further side, which is brought into view by libration.

Each of these grand divisions of 25° was further subdivided into twenty-five areas of 5° square, lettered in the same manner as the grand divisions with Greek letters, α to ω, the last space being left blank.

Finally, any object is distinguished by a number attached to the symbol denoting the small area of 5° square, which it is in, and also the quadrant. Thus I.A. α 50 would indicate that the small object numbered 50 was in the small 5° area marked α, which is found in the grand division A in the N.W. or No. 1 quadrant.

This method was comprehensive and complete, but the necessity of using four symbols to indicate an object proves very cumbersome and has not met with general adoption; besides which the boundary lines would in many cases intersect each other on the site of large formations, so that we might have an object like Plato cut up in such a way as to be more or less in three or four differently numbered areas.

The plan now suggested is that the Moon should be divided into districts, each district having within its limit some well-known formation to which minor objects would be referred.

The largest craters within this area would be lettered with capital Roman letters A, B, C, &c., and the twenty-six letters of the alphabet should suffice; but to make this certain it would be necessary to apply such letters only to craters above a certain diameter.

Thus, for instance, the walled plain Clavius would form a suitable district, and the craters on the floor and walls would be

lettered as at present and known as Clavius A, Clavius B, and so on.

Then all the minor objects such as craterlets, ridges, hills, clefts, and spots would be simply numbered, and would be known as Clavius 1, Clavius 2, and so on. Reference to the catalogue would give the nature of the object so numbered. In this system it will be seen that we get rid of the necessity of distinguishing each class of objects by a separate class of symbol, and this by the use of a number only; and, further, this method would have the advantage of crowding the maps with fewer signs or figures than any other which seeks to differentiate one class of object from another by use of a different symbol.

It may be urged as an objection to this scheme that it presupposes the existence of an accurate map to be divided up.

Such does not exist; but for practical purposes Schmidt's map should be found sufficiently accurate for this purpose, and I would propose that the divisions be first found on photographs and then transferred to the map. The sections or divisions on the map could then be enlarged to any given scale, and have printed upon them a suitable réseau to be used for plotting accurately the position of objects from the coordinates given in Mr. Saunder's catalogue.

Report on Observations of Jupiter, 1904–5, *made at Trincomali, Ceylon.* By Major P. B. Molesworth.

Part I. Preliminary.

Arrangement of Report.—The present paper is in continuation of the observations for 1903–4, given in the *Monthly Notices*, vol. lxv. No. 7. The nomenclature and arrangement are the same in both cases.

Telescope.—The 12¾-inch Calver equatorial was again used; but for the greater part of the observations no driving clock was available, as the clock had been sent home to Messrs. Ottway of Ealing for a new one to be made. At the end of January the new driving clock (a very fine one) was installed and used till the end of the observations.

Scope of the Observations.—Work was begun in the early mornings on 1904 June 3, and carried on steadily till June 20. At this point I was suddenly laid up with a sharp attack of pleurisy and fever, which necessitated my taking leave home as soon as I was convalescent. No astronomical work was done in England owing to ill-health, but observations were resumed as soon as I returned to Trincomali on 1904 November 26. Regular work was carried on up to 1905 February 13, when a spell of very bad observing weather set in, and very few more visual

observations were obtained. I was then experimenting with photographs of *Jupiter* with very promising results, considering the improvised apparatus and the low altitude of the planet.

The number of nights on which C.M. transits were taken was fifty-seven, distributed as follows each month :—

		No. of Nights.			No. of Nights.
1904	June	12	1905	Jan.	16
	Nov.	3		Feb.	11
	Dec.	14		March	1

The planet was observed visually for a total period of 100 hours, an average of about $1^h\ 40^m$ per night. One thousand five hundred and seventy-seven C.M. transits were taken in an average of 15·8 per hour. Five sets of measures were made for latitude with the bifilar micrometer in 1905 February and March. Experimental photographs were taken on nine nights in February and March, several negatives being obtained each night ; seven of the plates thus obtained were measured for latitude in an improvised measuring machine, and gave fair results which have been combined with those obtained with the micrometer (see page 104). One or two of the more prominent spots were also measured on the negatives for longitude.

Estimations of the colours and intensities of the belts were made on twenty-seven nights. Satellite phenomena were observed on twenty-seven nights, and careful satellite comparisons made on forty-five nights.

The long gap which broke the continuity of the observations from 1904 June to November has greatly detracted from their value. In a great many cases the identification of the markings was very uncertain, and I have therefore only worked out the rotation periods for those zones which I consider reliable.

The publication of results has again been greatly delayed by pressure of work.

Part II. Disc Observations.

I give a general description of the features noticed in the various zones and belts from south to north.

(*AA*) *S. Polar Region.*—Slightly striated, generally of a faint brownish-yellow tinge, the N. edge being slightly darker than the rest. The general tint is a colder grey than that of the N. Polar Region.

(*A*) *S.S. Zone.*—The dullest of all the zones, unusually dull this year ; generally slightly shaded and barely visible. Very few brighter spots were noticed in it, and those seen were of a very transient nature.

(*B*) *S. Temperate Belt.*—Still rather faint, colourless grey. Owing to uncertainties of identification I have not worked out the periods of the markings in it, but they appear to have practically the same motion as in previous years.

(*C*) *S. Temperate Zone.*—Shows very little change since the last apparition, but its general tone seems to be rather brighter. The mean period deduced from eleven spots this year is $9^h\ 55^m\ 20^s{\cdot}23$, showing a slight retardation compared with last year. Denning's two White Spots (*Observatory*, 1904 September, page 345) were repeatedly observed, and show very regular periods of $9^h\ 55^m\ 20^s{\cdot}08$ and $9^h\ 55^m\ 20^s{\cdot}39$ respectively.

(*D*) *S. Tropical Belt.*—Very distinct, dark, and knotted, but rarely seen double in 1904–5. The general tint is a decided slate-grey with sometimes a cast of blue. I have worked out the rotation periods of the spots in it, but in some cases the identification is rather doubtful. The mean period for most of the belt was $9^h\ 55^m\ 20^s{\cdot}63$, but two fairly well-marked spots in $\lambda^\circ = 60^\circ$ and 72° respectively appeared to have an abnormally slow period of $9^h\ 55^m\ 27^s{\cdot}8$. Possibly my identification is at fault.

The Red Spot.—The appearance of this feature is practically unchanged, and my description in 1903–4 still applies. The bay is now quite shallow and symmetrical, and its breadth possibly decreased slightly during the apparition. The dark curved wisp from the following shoulder to the S. Tropical Belt was almost invariably seen, while that from the preceding shoulder was absent except during the passage of the dark area. The following end of the Red Spot itself is still the darkest, but the ringed appearance of the spot was not noticed. The mean period for the year was $9^h\ 55^m\ 40^s{\cdot}00$.

Great S. Tropical Dark Area.—This is the subject of a separate note in Part IV. It was just coming into conjunction with the Red Spot bay when the observations broke off in June, and covered about 75° of longitude on either side of the bay. When next seen in November it appeared very much as in 1903–4, the total length of the shaded area being about 37°, decreasing to about 35° at the end of the apparition. The mean period of the preceding end was $9^h\ 55^m\ 21^s{\cdot}65$, and that of the following end (after conjunction with the Red Spot) $9^h\ 55^m\ 20^s{\cdot}25$, giving a mean period of $9^h\ 55^m\ 20^s{\cdot}95$. In the best observing conditions the complex structure of the dark area was very apparent, consisting of numerous smoky wisps springing from dark knots on the S. edge of S. Equatorial Belt. The brilliant white spots preceding and following the shaded area in the S. Tropical Zone are evidently related to it, and not due to contrast.

(*EFs*) *Other Spots in S. Tropical Zone and S. Edge of S. Equatorial Belt.*—There appear to be several well-defined dark "wave-crests" in the S. edge of S. Equatorial Belt separated by white bays. The best marked of these in 1904–5 almost all occurred in the 120° of longitude following the Red Spot bay. The influence of the "headlong rush" of the great dark area on these markings is very striking, and is dealt with in detail in the note in Part IV. The general tint of the S. Tropical Zone was a bright milky white, brightest just following the Red Spot

bay and on each side of the dark area. Wisps crossing the S. Tropical Zone were very rare except in the region of the dark area.

(*F*) *S. Equatorial Belt.*—Much the most prominent belt on *Jupiter* in 1904–5; broad and very dark, of a rich warm brown tint, which showed up very purple in twilight. The *S.* edge has been dealt with above. It is usually very sharp and clean-cut. The centre of the belt is irregularly rifted, the rift having a decided yellowish tinge in June which was not noticed later. The *N.* edge was more distinct and disturbed than in 1903–4, but it is by no means at a maximum of activity. Owing to the uncertainty of identification, I have not worked out the periods of the spots in this latitude; but it appears to differ little from that obtained in previous years.

(*GK*) *Equatorial Zone.*—Very white with little or no trace of yellow, the S. edge being, as a rule, considerably brighter and more disturbed than the N. edge, though the latter was brightest in 1903–4. The S. edge was active and contained numerous bright spots, while the N. edge was quiescent and remarkably uniform. The activity of the N. edge appears to depend entirely on the breadth and distinctness of the N. Equatorial Belt.

(*H*) *Equatorial Band.*—Very faint, discontinuous, and difficult to see, but certainly more frequently visible than in 1903–4. The wisps crossing the Equatorial Zone were also darker and more frequent this year, though still very difficult to see, except under the best conditions, and rarely traceable N. of the Equatorial band. I can see no signs of the symmetrical arrangement of these wisps described by some observers.

(*L*) *N. Equatorial Belt.*—Very faint and difficult to see well. It seems very narrow, with diffuse edges, and no darker condensations of any sort, being apparently at an absolute minimum of activity. So far as one can judge of colour in so faint an object, it seemed generally a faint colourless grey, with sometimes a slight blue tinge, but always much colder in tone than the S. Equatorial Belt.

(*M*) *N. Tropical Zone.*—Generally fairly bright, but uniform, with very few brighter spots. The activity of this zone also appears to vary with that of the N. Equatorial Belt.

(*MM*) *N. Tropical Belt.*—Very faint and nebulous, with occasionally a very slight bluish tinge. It is very narrow with indefinite edges.

(*NN*) *N. Temperate Zone.*—This is one of the most variable zones on the planet. It is sometimes very bright, and was once in 1904–5 rated as nearly as brilliant as the S. edge of Equatorial Zone. At other times it is very faint and inconspicuous, and generally rather uniform in tone. When brightest it has a milky-white tinge.

(*N*) *N. Temperate Belt.*—Faint and inconspicuous in June, distinct and considerably darker late in the apparition, when a decided sepia tinge was noticed in it. It formed the S. edge of

a very faint yellowish brown shade, which extended from it to the N. Pole.

(*P*) *N.N. Zone.*—Very dull and nearly always slightly shaded. There are very slightly brighter spots here and there in it, but nothing definite.

(*Q*) *N. Polar Region.*—Generally a very decided yellowish brown with once almost a pinkish tinge. It is very slightly striated, and is darkest along its southern edge.

Relative Brightness of Zones.—This was roughly gauged in the same way as in 1903–4 with the following results :—

(G)	S. Edge of Equatorial Zone	1·26
(E)	S. Tropical Zone	2·63
(K)	N. Edge of Equatorial Zone... ...	3·10
(M)	N. Tropical Zone	3·70
(C)	S. Temperate Zone	4·68
(NN)	N. Temperate Zone	5·06
(P)	N. N. Zone	6·87
(A)	S. S. Zone	7·93

Comparing these results with those obtained in 1903–4, the principal changes are the great falling-off in brightness of (K), the N. edge of the Equatorial Zone, and the increase of brightness in (G) S. edge of Equatorial Zone, and (C) S. Temperate Zone.

Rotation-periods in Different Zones.—Owing to the scantiness of the earlier observations, and the large gap (from June to November) which occurred between the earlier and later observations, the identification of many of the markings has been very difficult. I have therefore only worked out the periods for those zones in which the identification can be relied upon. The observations for the other zones have all been booked on the zone diagrams, and are available if required for comparison with the observations obtained by others.

The zones for which rotation-periods have been calculated are as follows :—

(C) S. Temperate Zone ; (D) S. Tropical Belt ; Red Spot ; Great S. Tropical Dark Area ; (EFs) Other Spots in S. Tropical Zone ; and S. Edge of S. Equatorial Belt.

Even in these zones I may have made mistakes in the identification of some of the spots, except in the case of the Red Spot, and the S. Tropical Dark Area, which are unmistakable. The shortness of the period of observation of the E and Fs spots may have led to error in identification, but I think the deduced period may be taken as fairly reliable.

The mean rotation-periods in different zones are given in Table I.

Measures.—No measures could be taken until very late in the

season owing to the absence of a driving-clock. After the new clock arrived I made five sets of measures with the filar micrometer in February and March. The measures were made in twilight, the planet being then very low and the definition, as a rule, unsatisfactory.

I have also measured the latitudes of the principal belts on seven of the best negatives, taken also in February and March. I used an improvised measuring machine, and the negatives are far from perfect, though they show a good deal of detail. The results are fairly accordant; and this method, if carried out with proper apparatus, would, I think, give very valuable results in the future.

In reducing the latitudes no allowance has been made for polar compression.

The means of both photographic and visual measures are given in Table II. The results, compared with 1903–4, seem to show an extension of the S. Equatorial Belt southwards, the motion being shared by the S. Tropical Belt. The N. Temperate Belt appears to have returned to the same latitude as in the early part of 1903.

I also measured the ratio between the equatorial and polar diameters on the photographs. The equatorial diameter is obviously affected by any trail of the image, however slight, during the exposure, which was in some cases as long as thirty or forty seconds. The polar axis was running rather jerkily, so that few of the images are good in this respect.

The mean value from my photographs was 1·000 : 1·084, as against Barnard's value of 1·000 : 1·069; but much better results will be obtained when the clock settles down.

Part III.—Satellite Observations.

These were carried on on the same lines as in previous years (*Monthly Notices*, vol. lxv. p. 696).

The result of the comparisons this year gives the relative brightness of the satellites as follows:

$$\text{III} = 1{\cdot}02 \qquad \text{II} = 2{\cdot}61$$
$$\text{I} = 2{\cdot}16 \qquad \text{IV} = 3{\cdot}96$$

These results seem to indicate a slight increase in the light of II. As far as I could judge, IV was, as a general rule, brighter and less bluish than in 1903–4, though still generally the faintest of the four.

The observations as regards colour, albedo, and variability are in complete agreement with those of 1903–4.

The distortion of the shadows near quadrature was well seen on several occasions.

Part IV.—General Remarks.

Cyclical variation in Period.—The observations this year have been too scanty to give good results, but when combined, in a few cases, with the published results of other observers they tend to confirm the conclusions I have already arrived at. The same holds good of the other two special points I referred to in my observations for 1903–4, viz. the *possible extension of the atmosphere of Jupiter* and the *visibility of the Red Spot bay.*

The value of a Driving-clock for delicate work.—The majority of the observations this year were made, as I have already mentioned, without a driving-clock. Hitherto I have regarded this adjunct as a luxury for visual work, but I am now convinced that it is an absolute necessity for the more delicate detail if the best work is to be done. The results this year are, I consider, less accurate than in previous years, and the fatigue to the eye is greatly increased by the strain of following a moving object. Even with the best slow motions there is a perceptible movement of the image when the screw is handled, and I have found it almost impossible to centre the fainter spots on the disc. The quantity as well as the quality of the observations has suffered owing to the number of fainter spots which have been missed. The average hourly number of transits taken this year was 15·8, as against 20 in 1903–4.

The Great S. Tropical Dark Area.—When the observations terminated abruptly in June this area was practically in conjunction with the Red Spot bay, the preceding end having passed the bay just before the observations began, and lying close to the zero meridian of system ii. The following end was still some distance following the bay, which shone up as a large white oval projected on the dark material. The area at the period covered a length of 70°–75° of longitude. I was prevented from watching the passage of the area further.

When next seen (in November) the dark area presented much the same appearance as in 1903–4, its total length being about 37°.

My observations of the preceding end, combined with published observations of Scriven Bolton and Flammarion, show a practically uniform period throughout the apparition, with a slight retardation to about the middle of October, followed by a slight acceleration.

Similarly the observations of the following end late in the apparition, combined with earlier observations of Flammarion, give a very uniform period of $9^h\ 55^m\ 20^s{\cdot}25$. Plotting this and prolonging it backwards, we get August 10 as the probable date of conjunction of the *following* end of the dark area with the *preceding* shoulder of the bay. Taking the observed positions of the following end of the area in June, and assuming the same period, we find that the following end should have reached the *following* shoulder also early in August, and would therefore

appear to have crossed the whole Red Spot bay (about 35° of longitude) almost simultaneously.

The same phenomena seem to have occurred at the last conjunction in 1902 July. As the preceding end of the area reached the following shoulder a dark wisp formed across the S. Tropical Zone at the preceding shoulder and moved down the zone at the normal speed of the dark area. As soon as the following end reached the following shoulder the dark area became complete on the other side of the bay, and moved off at its normal speed down the zone.

It seems impossible that there can be an instantaneous transference of material in this case from one side to the other of the bay, and some other explanation must be sought. The dark area seems to have passed neither *over* nor *under* the bay, but *round* it, by way of the S. Tropical Belt, completely skirting the oval of the bay without encroaching on it in any way. There seems to have been a progressive movement of material throughout the portion of the S. Tropical Belt south of the bay, the movement of the dark area into the belt following the bay causing the extrusion of an equal amount of dark material from the belt preceding the bay. The quantity of matter, so to speak, contained in the belt remained constant, while it acted almost like an incompressible fluid bounded rigidly by the oval of the Red Spot bay.

(This supposed action may be illustrated by taking a slightly curved tube, open at both ends, to represent the S. Tropical Belt at the Red Spot bay. The dark material may be represented by steel balls of such a size as to pass down the tube. If the tube be filled with steel balls and another ball be pushed into one open end, all the balls move, and one is pushed out of the other open end.)

Another peculiarity I have noticed with the dark area is its effect on the rotation-period of the dark "wave crests" in the S. Edge of S. Equatorial Belt and the intervening white spots. Before the formation of the dark area these markings had a period practically identical with that of the Red Spot; but since its formation (1901 May) their period has been very variable, being considerably retarded as the dark area approaches them, and accelerated directly after its passage, gradually returning to the normal. Their behaviour reminds me very much of the buoys in the Suez Canal during the passage of a large vessel. As the ship approaches the buoys are drawn in towards it, and after it has passed follow it as far as their mooring permits. If the moorings possessed considerable elasticity the analogy would be still more complete.

From a careful study of all the phenomena connected with the dark area, I am convinced that it is a well-defined mass of material moving with a high velocity through a slower current, but diverted and repelled in some mysterious way as it nears the Red Spot bay.

The true explanation of these phenomena would do much to increase our knowledge of the atmospheric conditions of *Jupiter*.

Visual Estimates versus *Micrometer Measures.*—There has been a good deal of controversy as to the relative values of these two methods of fixing the longitudes of the markings on *Jupiter*. Personally I am inclined to think that with small sharply defined markings there is little to choose between the two methods if employed by experienced observers. If the markings are very faint or very diffuse, I consider that eye estimates are more likely to give accurate results. Personally, with a micrometer, after taking every precaution as regards focus and parallax, I lose a delicate spot completely as soon as I try to place the wire on it, and I find the same difficulty with the fainter belts when taking measures for latitude.

One great cause of inaccuracy in visual work is, in my opinion, the use of an ephemeris calculated out beforehand for each spot. Each observation should be made perfectly independently without the slightest knowledge of the theoretical time of transit.

My own practice is to note the time of transit of *every* spot which can be seen with sufficient distinctness during the time of observation. The longitudes are never worked out till the transits are booked in the "transit ledger" (generally next day). By this means any possibility of bias is avoided. It is most important, however, as Stanley Williams has pointed out (*Zenographical Fragments*, vol. i. p. 4), that in visual observations the same eye should always be used, and that the line joining the eyes should be kept parallel to the direction of the belts. This, with a Newtonian with revolving head, can generally be easily arranged.

I hope that Professor Hough's strictures on eye estimates will not deter observers from pursuing this extremely valuable work.

TABLE I.

Average Rotation-periods in Different Zones.

Zone.	Approx. Latitude.	No of Spots.	Average No. of Obs.	Average Elapsed Rotations.	Rotation-period.
	°				h m s
White Spots. S. Temperate Zone (C)	−35	11	9·7	453	9 56 20·23
Dark Spots. S. Tropical Belt (D)	−28	2	9·5	583	9 55 27·78*
Dark Spots. S. Tropical Belt (D)	−28	7	17·9	472	9 55 20·63†
Red Spot	−15	3	19·0	672	9 55 40·00
Great S. Tropical Dark Area...	−21	4	26·5	612	9 55 20·95
Other spots in S. Tropical Zone (E) and S. Edge of S. Equatorial Belt (Fs) ...	−15 to −21	9	9·2	209	9 55 53·97

* Abnormal. † Normal.

TABLE II.

Latitudes of Belts from Measures.

	Distance from Centre of Disc at Mean Distance 5·20				
	(D) Centre of S. Trop. Belt.	(Fs) S. Edge of S. Eq. Belt.	(Fn) N. Edge of S. Eq. Belt.	(L) Centre of N. Eq. Belt.	(N.) Centre of N. Temp. Belt.
Average of 5 Visual Measures ...	$-9''.52$	$-6''.41$	$-3''.00$	$+2''.70$	$+8''.72$
Average of 7 Photographic Measures	$-9·70$	$-7·12$	$-2·70$	$+2·68$	$+8·85$
Mean ...	$-9·61$	$-6·77$	$-2·85$	$+2·69$	$+8·78$
Apparent latitude	$-32°.33$	$-22°.13$	$-9°.13$	$+8°.60$	$+29°.25$
Correction to centre at mean date (1905 March 4)	$+2·74$	$+2·74$	$+2·74$	$+2·74$	$+2·74$
True latitude (ϕ) ..	$-29·59$	$-19·39$	$-6·49$	$+11·34$	$+31·99$

The Annular Nebula in Lyra (M 57). By E. E. Barnard.

In *Monthly Notices* of the Royal Astronomical Society for 1900 January I have given a paper on the Annular Nebula of *Lyra* (*M* 57), in which it was shown that measures of the central star of the nebula with reference to a 12^m star (a) following, made by Professor Burnham in 1891, consistently differed from measures made by the writer in 1898 and 1899 by 1° in angle and 1″ in distance. The distance had apparently diminished, and it was there suggested that this difference might possibly be due to motion in the nebula.

Professor Asaph Hall had measured a number of small stars about the nebula in 1877 with reference to a. These stars were remeasured by me in 1899, but they did not indicate any motion in a; they seemed to be stationary, with the possible exception of the star f. Professor Hall did not see the central star, and hence there are no measures prior to those of Professor Burnham.

In 1900 February Professor Scheiner and I measured at Potsdam a negative made by Dr. Scheiner in 1894 October 29 (see *Monthly Notices*, January 1900, p. 257), which gave results that did not verify the suspected change in the position of the nucleus.

In 1900 September Professor F. P. Leavenworth, of the University of Minnesota, measured these stars and the nucleus on several negatives taken by him in 1897–1900 (see *Monthly Notices*, vol. lxi. p. 25).

In 1902 Mr. Burt L. Newkirk, of Minneapolis, from all the measures, determined the proper motion and the parallax of the

nebula in an inaugural dissertation for the Doctor's degree at Munich—"Eine Untersuchung der Parallaxe des Zentralsternes des Ringnebels in der Leier" (Munich, 1902).

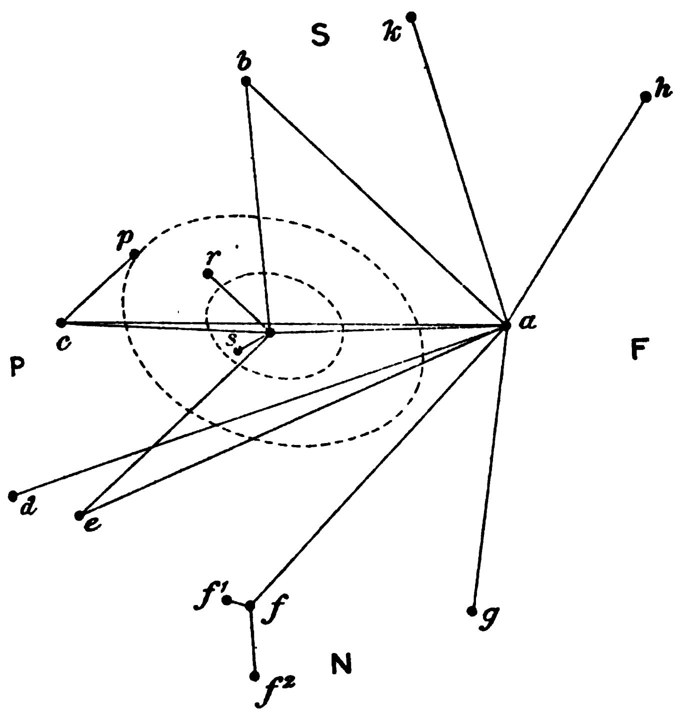
For the proper motion of the central star Dr. Newkirk got the values

$$\Delta\alpha = -0^s{\cdot}012 \pm 0^s{\cdot}0012$$
$$\Delta\delta = +0''{\cdot}10 \pm 0''{\cdot}029.$$

These would give the following for the direction and amount of the annual motion of the central star :

Direction of motion pos. ang.		$303^\circ{\cdot}7$
Amount	„	$0''{\cdot}180.$

Dr. Newkirk found for the parallax a value of $0''{\cdot}10$.



As this was the first nebula whose distance and proper motion had ever been determined it became of the greatest importance to verify the results.

To strengthen the value of the measures made by me in 1898–9 I have recently measured two photographs of the nebula

which I made with the 40-inch telescope and a colour-screen on 1900 September 2 and September 3. These agree quite closely with the visual measures, and give a good foundation for the comparison of any measures made hereafter.

Sufficient time having elapsed to test the above results, in 1903 and 1904 I again measured the position of the nucleus with respect to *a*. According to Dr. Newkirk's value of the motion the total displacement of the nucleus in the five years that had elapsed would be 0″·90; and in the direction of *a* the displacement would be 0″·75, which would be easily measurable. It will be noticed that the direction of motion given by Dr. Newkirk would increase the distance from the star *a*, which cannot be reconciled with the early and late measures of the distance from the nucleus to *a*.

The results from these measures of 1903–4 do not verify the motion derived by Dr. Newkirk. They seem to imply that there has been no measurable change in the position of the nucleus or central star, and they certainly show that the relatively large motion assigned it does not exist. Dr. Newkirk's motion lies nearly in the direction of the star *e*, and to further test his values I have recently made on two nights measures of the position-angle and distance of *e* from the nucleus. This distance should have diminished an entire second of arc, but the measures show no certain change.

As Dr. Newkirk's parallax for the central star depends upon the proper motion which he determined, and which is shown not to exist, the parallax itself must be fallacious.

The discordance in the position of the star *f* as measured by Professor Hall and myself led me to suppose that *f* had a small proper motion, but the measures of the present year show that there is no definite motion even in this star. Indeed, everything in the immediate region of this nebula seems to have the usual fixity of the ordinary small stars.

In the paper for *Monthly Notices* for 1900 January, p. 250, attention was called to a 17^{m} star which was at the limit of the 40-inch visually, and which I could not measure. On 1900 July 29, with good seeing, this star could be seen very steadily. If necessary, its position could have been measured readily. This star should not, therefore, be considered as the limit of the 40-inch visually under good conditions. On this same occasion I could see the second star inside the ring. It was north preceding the nucleus, and was estimated to be $8\frac{1}{2}''$ distant in the direction of the star *d*, or in position-angle $300° \pm$. This agrees closely with the position subsequently measured on the photographs. At this time the central star was bright and easy, and was estimated to be 13 magnitude.

Conditions of steadiness make a very great difference in the visibility of a faint star in a large telescope. The difference is still greater if the star happens to be immersed in nebulosity.

On the two photographs of 1901 September 2 and September 3

I have measured the position of this second star in the ring, and also another star on the inner edge of the preceding part of the ring. This last star could be measured on only one plate.

Measures of the Photographs.

Nucleus and *a*.

Sept. 2	1901·671	88° 55′	60″·73
3	·673	89 01	60·56
	1901·67	88 58	60·64

Nucleus and *b*.

Sept. 2	1901·671	185° 21′	64″·98
3	·673	185 21	64·87
	1901·67	185 21	64·92

Nucleus and *c*.

Sept. 2	1901·671	268° 22′	54″·83
3	·673	268 17	54·84
	1901·67	268 19	54·83

Nucleus and *e*.

Sept. 2	1901·671	312° 50′	71″·14
3	·673	312 49	71·12
	1901·67	312 49	71·13

***a* and *b*.**

Sept. 2	1901·671	225° 28′	93″·71
3	·673	225 21	93·79
	1901·67	225 25	93·75

***a* and *c*.**

Sept. 2	1901·671	268° 39′	115″·58
3	·673	268 40	115·31
	1901·67	268 39	115·45

***a* and *d*.**

Sept. 2	1901·671	286° 42′	137″·29
3	·673	286 47	137·30
	1901·67	286 45	137·30

K

a and *e*.

Sept.	2	1901·671	292° 46′	122″·38
	3	·673	292 40	122·33
		1901·67	292 43	122·35

a and *g*.

Sept.	2	1901·671	350° 28′	76″·31
	3	·673	350 28	76·21
		1901·67	350 28	76·26

a and *f*.

Sept.	2	1901·671	314° 53′	99″·84
	3	·673	314 47	99·88
		1901·67	314 50	99·86

f and *f*1.

Sept.	2	1901·671	261° 11′	4″·98
	3	·673	262 12	4·93
		1901·67	261 41	4·95

f and *f*2.

Sept.	2	1901·671	3° 08′	18″·19
	3	·673	3 22	18·15
		1901·67	3 15	18·17

a and *h*.

Sept.	2	1901·671	148° 16′	70″·73
	3	·673	148 10	70·82
		1901·67	148 13	70·77

a and *k*.

Sept.	3	1901·673	195° 56′	84″·71

c and *p*.

Sept	2	1901·671	133° 48′	27″·41
	3	·673	133 41	27·53
		1901·67	133 45	27·47

Nucleus and *s*.

Sept. 2	1901·671	300° 36′	10″·23
3	·673	300 44	10·31
	1901·67	300 40	10·27

Nucleus and *r*.

Sept. 3	1901·673	223° 31′	21″·83

The exposure times for these photographs were

1901	h m		h m	
Sept. 2	19 40	to	23 15	Sid. time
„ 3	8 30	„	11 40	Central standard time.

These plates were measured on a Gaertner Measuring Machine, with which position angles and distances can be determined. When they were originally made no such machine was available.

On the plate of September 3 *Atlas* and *Pleione* and *Electra* and *Celæno* of the *Pleiades* were allowed to trail. A few short exposures on these stars were also impressed on the same plate, which remained undisturbed in the telescope. From these the parallel and scale values were determined in the measuring machine, and were used for the reduction of the measures. The parallel in the plate of September 2 was determined by a comparison of the known angles obtained from the other plate. These measures are therefore entirely independent of the micrometer of the 40-inch.

As the two photographs were made with a yellow colour screen and Cramer Instantaneous Iso plates the magnitudes of the small stars on the plate will not be very different from what they are visually. I have thus compared several of the stars in the nebula with some of those outside, whose magnitudes I had already estimated (*Monthly Notices*, vol. lx. p. 248).

Following are the magnitudes thus derived :—

p = 14^m·8	from comparisons	with	6	different stars
s = 14·2	„	„	3	„
r = 14·7	„	„	3	„
nucleus = 13·6	„	„	9	„

Hence none of these stars would be difficult if free from the nebula.

The measures made in 1903 and 1904, especially the distances, are not very accordant. Good nights could not be selected for the work, and the nucleus was measured at times when the seeing was so bad that the measures should not have been made. There are enough observations, however, to eliminate the effect of poor

*K 2

seeing, and I think the mean results are satisfactory. No observation has been rejected. On two dates the nucleus could not be seen after the angles were measured, and the distances could not be obtained.

These observations follow :—

Nucleus and *a*.

(1903).

July 21	1903·552	88°·44	59″·83
27	·569	88·40	...
Aug. 10	·607	89·01	60·50
11	·610	88·94	60·36
17	·626	88·91	60·65
18	·629	88·35	60·89
24	·645	89·02	61·30
31	·664	89·65	60·73
Sept. 1	·667	88·71	60·35
7	·684	88·82	60·67
21	·722	88·79	60·86
22	·725	88·74	60·68
28	·741	88·86	61·22
Oct. 13	·782	88·84	61·30
27	·821	88·52	60·88
	1903·669	88·80	60·73

(1904).

Apr. 26	1904·319	89°·17	61″·39
May 17	·376	89·35	60·73
June 14	·453	89·07	61·08
July 9	·521	88·66	60·67
Aug. 1	584	88·48	...
26	·653	88·69	60·52
	1904·484	88·90	60·88

Following are the measures made in 1905 :—

Nucleus and *e*.

Nov. 26	1905·904	312°·87	71″·38
28	·909	312·85	70·91
	1905·91	312·86	71·14

a and *f*.

Nov. 26	1905·904	314°·78	100″·08
28	·909	314·75	100·11
	1905·91	314·76	100·09

f and *f*¹.

Nov. 28	1905·909	258°·32	5″·15

In these observations the conditions were very poor, and the nucleus was very difficult. The images of *f* and *f*¹ were very much blurred, and the measures difficult and uncertain.

Following is a collection of all the measures of the nucleus and of the small stars near the nebula that are known to me :—

Nucleus and *a*.

Burnham	1891·45	87°·8	61″·69	(5n)
Scheiner and Barnard	1894·83	88·92	60·71	(1n) photo
Barnard	1898·60	88·77	60·70	(5n)
Barnard	1899·48	89·14	60·66	(5n)
Leavenworth ...	1899·55	89·29	60·56	(4n) photo
Barnard	1901·67	88·96	60·64	(2n) photo
Barnard	1903·67	88·79	60·73	(15–14n)
Barnard	1904·48	88·90	60·88	(6–5n)

Nucleus and *b*.

Barnard	1899·58	185°·37	65″·04	(3n)
Leavenworth ...	1899·84	186·61	65·17	(1n) photo
Barnard	1901·67	185·35	64·92	(2n) photo

Nucleus and *c*.

Barnard	1899·53	267°·59	54″·92	(3n)
Leavenworth ...	1900·13	268·82	55·34	(2n) photo
Barnard	1901·67	268·32	54·84	(2n) photo

Nucleus and *e*.

Barnard	1899·49	312°·38	70″·96	(3n)
Leavenworth ...	1899·55	312·80	71·32	(4n) photo
Barnard	1901·67	312·82	71·13	(2n) photo
Barnard	1905·91	312·86	71·14	(2n)

a and *b*.

Hall ...	...	1877·6	225°·5	93″·90	(2n)
Barnard	...	1899·51	225·76	93·58	(3n)
Leavenworth	...	1899·84	225·57	94·38	(1n) photo
Barnard	...	1901·67	225·41	93·75	(2n) photo

a and *c*.

Hall ...	...	1877·6	268°·0	115″·83	(2n)
Barnard	...	1899·50	268·78	115·58	(3n)
Leavenworth	...	1900·13	268·63	115·55	(2n) photo
Barnard	...	1901·67	268·66	115·44	(2n) photo

a and *d*.

Hall ...	...	1877·6	286°·9	138″·58	(2n)
Barnard	...	1899·50	286·96	137·60	(4–3n)
Leavenworth	...	1900·17	286·76	137·44	(3n) photo
Barnard	...	1901·67	286·74	137·30	(2n) photo

a and *e*.

Hall ...	...	1877·6	292°·6	122″·90	(2n)
Barnard	...	1899·47	292·81	122·13	(2n)
Leavenworth	...	1899·55	292·71	122·37	(4n) photo
Barnard	...	1901·67	292·72	122·35	(2n) photo

a and *g*.

Hall ...	...	1877·6	350°·5	77″·18	(2n)
Barnard	...	1899·51	350·78	76·16	(4n)
Leavenworth	...	1900·17	350·32	76·46	(3n) photo
Barnard	...	1901·67	350·47	76·26	(2n) photo

a and *f*.

Hall ...	...	1877·6	313°·7	101″·79	(2n)
Barnard	...	1899·50	315·39	99·97	(2n)
Barnard	...	1901·67	314·83	99·86	(2n) photo
Barnard	...	1905·91	314·76	100·08	(2n)

f and f^1.

Hall ...	...	1877·6	253°·3	3″·96	(2n)
Barnard	...	1899·53	262·95	4·89	(3n)
Barnard	...	1901·67	261·69	4·95	(2n) photo
Barnard	...	1905·91	258·32	5·15	(1n)

		f and *f*[2].		
Hall	1877·6	4°·8	17″·31	(2n)
Barnard	1899·52	3·42	17·86	(2n)
Barnard	1901·67	3·25	18·17	(2n) photo
		a and *h*.		
Barnard	1899·47	148°·14	70″·52	(3n)
Leavenworth ...	1899·55	148·59	70·42	(4n) photo
Barnard	1901·67	148·22	70·77	(2n) photo
		a and *k*.		
Barnard	1899·59	195°·86	85″·16	(5n)
Barnard	1901·67	195·93	84·71	(1n) photo
		c and *p*.		
Barnard	1899·52	133°·34	27″·24	(2n)
Barnard	1901·67	133·74	27·47	(2n) photo
		Nucleus and *s*.		
Barnard	1901·67	300°·66	10″·27	(2n) photo
		Nucleus and *r*.		
Barnard	1901·67	223°·52	21″·83	(1n) photo
		Nucleus and *d*.		
Leavenworth ...	1900·17	299°·78	81″·97	(3n) photo
		Nucleus and *g*.		
Leavenworth ...	1900·17	32°·50	90″·13	(3n) photo
		Nucleus and *h*.		
Leavenworth ...	1899·55	121°·18	113″·84	(4n) photo

As stated in my previous paper, *Monthly Notices*, vol. lx. p. 252, the final reduction of all the measures of the micrometer screw gave a less value for it than was used in my previous measures. The present observations are reduced with the adopted value of 9″·665. Where my former measures are quoted in the present paper they have been re-reduced with the above value of the screw.

Yerkes Observatory, Williams Bay, Wis.:
1905 *December*.

Elements and Light Curve of RV Lyræ (Ch. 6915).

By A. Stanley Williams.

$$\text{R.A.} = 19^{h}\ 10^{m}\ 49^{s} \quad \text{Decl.} = +32^{\circ}\ 10'.1\ (1855)$$
$$\text{,,} \quad = 19\ 12\ 31 \quad \text{,,} \quad = +32\ 14.8\ (1900)$$

Preliminary elements of variation of this Algol-type variable were published in the *Astronomische Nachrichten*, No. 3811, the period being there given as $3^{d}.598883$. The minima of this star are rather faint for observation with a 6½-inch aperture, but observations have been made here whenever practicable; and although the results are neither so numerous nor so satisfactory as might be wished, yet it now seems desirable to discuss the results so far obtained, and to derive improved elements of variation, particularly since it is now practicable to connect the more recent observations with an early Harvard College photographic one.

Table I. contains the comparison stars employed and the adopted light-scale. The latter is a somewhat provisional one, as a complete discussion of the results is reserved to the time when more observations are available; but it appears to be quite satisfactory, and it does not seem likely that any material modification will be made hereafter. The magnitudes in the fifth column of the table are based on the assumptions that the magnitude of the star A is 8·61, and the value of a step 0·05 magnitude. The star *f*, it may be mentioned, is just clearly and steadily visible on a clear night in a 6½-inch reflector.

Table I.

Comparison Stars and Light-scale.

Star.	B.D. No.	B.D. Mag.	Light.	Adopted Mag.
A	+32°3376	9·2	0·0	8·61
B	+32·3377	9·1	14·2	9·32
C	+32·3380	9·4	26·7	9·94
b	...	...	41·2	10·67
c	...	...	63·6	11·79
d	...	...	63·6	11·79
e	...	...	72·6	12·24
f	...	...	78·2	12·54

The comparison stars are shown in the adjoining little chart based on the B.D. and constructed for 1855. It should be mentioned that the fainter stars have only been inserted by estimation from a photograph, but the positions will probably be sufficiently accurate for the purpose of identification.

Table II. contains the observed heliocentric Greenwich mean times of minimum.* The last eleven of these have been derived from the visual observations by means of a mean light-curve. The weights in the last column are on a scale ranging from 1 to 5. A weight 5 implies that the observations are numerous, very accordant, and distributed pretty uniformly on either side of the minimum. The time of the observation of 1901 October 7 was derived from a photograph obtained here with a 4·4-inch portrait lens, on the assumptions that the photographic light-curve and the photographic brightness of the variable and of the comparison star *c* respectively are the same as the visual ones. On the photograph the variable is equal in brightness to this star *c*. Particulars of an early Harvard College photograph, showing the

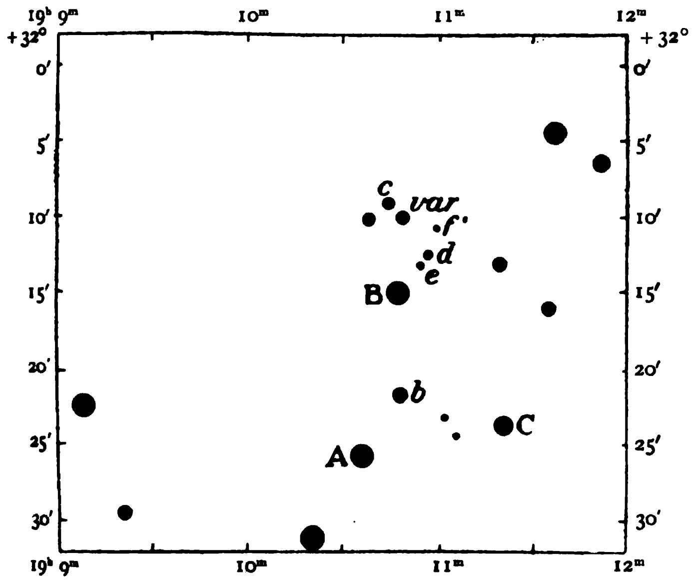


Chart of the Region of *RV Lyræ.*

variable faint, have been given by Professor E. C. Pickering in H.C.O. Circular, No. 66 (*A.N.* 3833). A preliminary discussion of the observations showed that this photograph must have been taken when the star was increasing in brightness, and the first minimum of the table was assumed to have occurred $3^h\ 30^m$ earlier than the time given for the photograph.

* In addition to the minima contained in the table Dr. E. Hartwig observed the star decrease 1·3 mag. between $9^h\ 22^m$ and $11^h\ 19^m$ (Bamberg mean time) on the night of 1902 Aug. 16 (*A.N.* 3811). The computed time of minimum is $12^h{\cdot}05$ G.M.T. = $12^h\ 49^m$ Bamberg mean time.

TABLE II.

Observed and Computed Times of Minimum.

E.	Observed Minimum.			h m	J.D. 241+	Computed Minimum.	O–C. m	wt.
−836	1893	July	11	14 44·9	2658·6145	2656·6148	− 0·4	ph.
0	1901	Oct.	7	9 21·8	5665·3901	5665·3897	+ 0·6	ph.
67	1902	June	5	11 45·8	5906·4902	5906·5236	−48·1	1
77		July	11	12 16·9	5942·5117	5942·5137	− 2·9	4
79		,,	18	17 01·9	5949·7096	5949·7117	− 3·0	2
82		,,	29	12 04·8	5960·5034	5960·5088	− 7·8	4
92		Sept.	3	11 45·2	5996·4897	5996·4989	−13·2	4
167	1903	May	31	10 19·5	6266·4302	6266·4249	+ 7·6	3
197		Sept.	16	9 32·3	6374·3974	6374·3953	+ 3·0	3
289	1904	Aug.	12	12 21·3	6705·5148	6705·5045	+14·9	5
297		Sept.	10	7 19·8	6734·3054	6734·2966	+12·7	1
299		Sept.	17	12 10·3	6741·5071	6741·4946	+18·0	1
369	1905	May	27	10 19·3	6993·4301	6993·4255	+ 6·6	2

The following are the fresh elements of variation.

$$\text{Minimum} = 1901 \text{ Oct. } 7,\ 9^{h}\ 21^{m}{\cdot}2\ (\text{G.M.T.}) + 3^{d}\ 14^{h}\ 22^{m}\ 34^{s}{\cdot}7\text{E}$$
$$= \text{J.D. } 2415665{\cdot}3897 + 3^{d}{\cdot}599013\ \text{E}$$

The computed times of minimum and the differences O—C will be found in the last two columns of the above table. These differences are not particularly large with the exception of that for 1902 June 5; but with regard to this it should be remarked that on the night in question only two glimpses of the star could be obtained through nearly continuous cloud, and that since these two glimpses, separated by an interval of 16^{m}, seemed to show that the variable was then decreasing in brightness, whereas it must actually have been increasing, it is probable that one if not both of the observations were more or less affected by cloud.

But the grouping of the plus and minus differences in the table appears to indicate either the existence of systematic error in the observations or else that the adopted period is a little too short. As regards the latter, however, it does not seem permissible to make the time of minimum on 1893 July 11 any earlier than that which has been adopted, so that this early Harvard photograph appears to be conclusive against the adoption of a longer period. The star was assumed to be 3^{h} 30^{m} past minimum at the time of the photograph, and if the time of minimum were put any—even a few minutes—earlier, the star would only have been very slightly fainter than normal. There is, however, a cause which might have produced a systematic

discordance such as that shown. The mean light curve from which all the times of minimum were derived was constructed from the observations of 1902, and on the assumption that the increasing phase corresponded to the decreasing phase, for nearly all the observations of any value up to that time had been made when the star was decreasing in brightness. But it will be seen from the mean light curve in Table III. that the increasing phase lags a little behind the decreasing one. Now the minima subsequent to 1902 were chiefly observed only in the increasing phase, that of 1904 September 17 being the only one observed during the decreasing phase alone.* Hence it will be evident that the result of using this mean light curve will be to make these subsequent minima, observed chiefly in the increasing phase, a little later than those of 1902, which were observed chiefly only in the decrease. In order to test this point the times of minimum were redetermined by means of the light curve in Table III., the corrections to the times in Table II. being as under :

Date of Minimum.			Correction.	Date of Minimum.			Correction.
			m				m
1902	June	5	+6	1903	May	31	− 5
	July	11	+3		Sept.	16	0
	„	18	−4	1904	Aug.	12	− 9
	„	29	−1		Sept.	10	+ 2
	Sept.	3	−1		„	17	−11
				1905	May	27	− 3
		Mean	= +0m·6			Mean	= − 4m·3

The mean correction indicated for the five minima of 1902 is $+0^{m}\cdot6$, and that for the six subsequent minima is $-4^{m}\cdot3$. Hence there is a difference of about five minutes in the right direction. The whole of the systematic difference shown by Table II. does not appear, however, to be accounted for in this manner, so that it seems possible that the real period may be very slightly longer at present than that adopted. Unfortunately the observations of this variable have been almost a complete failure during the present year, owing to unfavourable weather, so that it does not seem safe to conclude anything more definite at present.

The mean light curve given in Table III. has been derived from 92 *good* observations, all doubtful ones having been rejected. It appears to be quite reliable and satisfactory excepting just at the beginning of the decrease and at the end of the increase, where the observations are at present only few in number, so that the exact form of the curve at these two points is somewhat uncertain.

* The minimum of 1904 Aug. 12 was observed during both the decrease and the increase.

TABLE III.

Light Curve of RV Lyræ.

Time.	Brightness Before Min.	Brightness After Min.	Time.	Brightness Before Min.	Brightness After Min.
h m			h m		
4 00	49·0	50·6	1 50	74·5	76·7
3 50	49·5	52·0	1 40	76·0	77·9
3 40	51·0	53·6	1 30	77·5	79·0
3 30	53·2	55·6	1 20	78·7	79·9
3 20	55·4	57·7	1 10	79·7	80·7
3 10	58·0	59·9	1 00	80·5	81·2
3 00	60·5	62·5	0 50	81·1	81·6
2 50	62·6	64·7	0 40	81·7	82·0
2 40	65·3	67·0	0 30	82·0	82·1
2 30	67·4	69·3	0 20	82·2	82·2
2 20	69·2	71·4	0 10	82·3	82·3
2 10	71·2	73·5	0 00	82·4	82·4
2 00	72·8	75·1			

The brightness of the variable according to the light-scale of Table I. is given for every ten minutes of time before and after minimum in the above table. The normal brightness of the star is 49·0 of the scale, corresponding to 11·06 mag. The minimum brightness is 82·4 = 12·73 mag. There is no stationary period at minimum. The table shows a slight though distinct difference in the form of the curve before and after minimum. The star appears to take a little longer in recovering its light than it did in losing it. The difference is, however, not great, and may perhaps be only subjective.

Hove: 1905 *December* 26.

Elements and Light Curve of VW Cygni (Ch. 7268).
By A. Stanley Williams.

$$\text{R.A.} = 20^{h}\ 09^{m}\ 37^{s} \quad \text{Decl.} = +34^{\circ}\ 03'\!\cdot\!7\ (1855)$$
$$\text{,,} \ = 20\ 11\ 21 \quad \text{,,} \ = +34\ 11\cdot 8\ (1900)$$

Preliminary elements of variation of this Algol-type variable star have been published in the *Astronomische Nachrichten*, No. 3899, the period being there given as 8·4326 days. The minima of this star are difficult to observe, owing to the long duration of the stationary period (7 hours). In fact I have not

yet been able to observe a minimum in a complete manner; that is, to observe both the decreasing and increasing phases on the same night. Hence an outline of the manner in which the improved elements of variation and the light curve have been derived may not, perhaps, be without interest.

The comparison stars used and the adopted light scale are given in Table I., together with the assumed stellar magnitudes of the stars, based on the assumptions that the star *a* is 8·2 mag. and the value of a step is 0·05 mag. The adjoining little chart

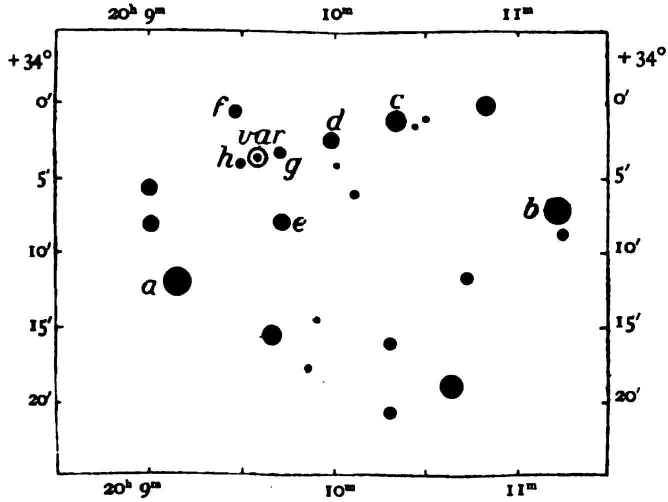


Chart of the Region of *VW Cygni.*

(for 1855) will assist in identifying the comparison stars and the variable. The fainter stars have, however, only been inserted in this by estimation.*

TABLE I.

Comparison Stars and Light Scale.

Star.	B.D. No.	B.D. Mag.	Light.	Assumed Mag.
a	+34°3936	8·5	80·0	8·20
b	+34°3953	8·7	65·8	8·91
c	+34°3946	9·2	52·3	9·58
d	+34°3942	9·5	41·8	10·11
e	...	...	37·8	10·31
f	...	...	26·5	10·87
g	...	...	12·5	11·57
h	...	...	2·5	12·07

* The B.D. positions of two or three of the stars shown on the chart are apparently slightly in error. In particular the B.D. declination of the star *c* would appear to be about ¾′ too small, and that of the star *d* about ¾′ too large.

There are eight minima available for the purpose of deriving an improved value of the period of variation.* On two nights the star was observed during the decreasing phase, and on the remaining six nights during the increasing phase. Since the star was never observed during both phases on the same night, it is impossible to determine the point of minimum, or the middle of the stationary period, directly from the observations. As there is an interval of only two periods between the two observations of the decreasing phase, these two observations are of little use for determining the period of variation. It was necessary, therefore, to rely in the first place upon the six observations of the increasing phase. A rough † light curve (Curve A) had already been formed from the early observations of 1903, and by means of this curve the times (T_2) when the variable was of brightness 20 on the light scale of Table I. were carefully determined. This brightness 20 was chosen because it was roughly near the average brightness of the observations made during the increasing phase. The times (T_1) when the variable was of corresponding brightness were also determined for the two minima observed during the decreasing phase. Table II. contains the observed times of T_2.

TABLE II.

Observed and Computed Times of T_2.

E.	Observed T_2.	Computed T_2.	O—C.
			d
80	J.D. 2416340·39	6340·379	+0·011
89	6416·24	6416·255	− ·015
115	6635·44	6635·450	− ·010
124	6711·34	6711·326	+ ·014
173	7124·43	7124·425	+ ·005
175	7141·28	7141·286	− ·006

The above observations on a least-square reduction gave $8^{d}·4306$ as the corrected period of variation. The computed times of T_2 and the residuals O − C will be found in the table. The mean of the times T_2 is J.D. 2416728·187. The two observations of T_1 were then reduced to the same date, the mean of the two being J.D. 2416727·759. The mean of the times T_1 and T_2 was assumed to be the time of minimum, so that the improved elements (Elements II.) reduced to E = 0 are :

$$\text{Minimum} = \text{J.D. } 2415665·717 + 8^{d}·4306 \text{ E}$$

* Four observations made during the minimum which occurred on the night of 1903 September 7 are of no use for this purpose, since they all relate to the long stationary period.

† This curve differs only slightly from the light curve (C) contained in Table III.

All the good * observations (60 in number) made when the star was below normal brightness were then reduced with these elements, and a fresh light curve (B) drawn on the assumption that the increasing and decreasing phases were exactly similar. This was rendered necessary owing to the fact that there are still two considerable gaps where there are no observations available. But it appeared that the observations would be somewhat better represented by a slight departure from exact similarity in the increasing and decreasing phases, and a few local corrections were accordingly made, resulting in the third light curve (C), which is given in Table III., where the brightness of the star is stated according to the light-scale of Table I. for every half-hour before and after minimum.

TABLE III.

Light Curve of VW Cygni.

Time.	Brightness.		Time.	Brightness.	
	Before Min.	After Min.		Before Min.	After Min.
h m			h m		
10 30	45·2	45·2	5 00	19·6	20·0
10 00	45·0	45·0	4 30	15·8	16·1
9 30	44·0	43·0	4 00	11·7	11·9
9 00	42·0	41·0	3 30	6·5	6·5
8 30	39·5	39·0	3 00	6·5	6·5
8 00	37·0	37·0	2 30	6·5	6·5
7 30	34·4	34·8	2 00	6·5	6·5
7 00	31 8	32·6	1 30	6·5	6·5
6 30	29·0	30·0	1 00	6·5	6·5
6 00	26·1	27·0	0 30	6·5	6·5
5 30	23·0	23·5	0 00	6·5	6·5

The above light curve must be very near the true one, though there are no observations at present during the first part of the decrease and again at the end of the stationary period and the commencement of the increase. The middle point of the stationary period has been assumed to be the minimum point, and the times of minimum † have been determined by means of the above light curve, and are given in Table IV.

* A few observations made under unfavourable circumstances were rejected.

† These are geocentric Greenwich mean times, the correction for the light equation not having been taken into account in the present investigation.

TABLE IV.

Observed and Computed Times of Minimum.

E.	Observed Minimum.					Computed Minimum.	O—C.
		d	h	m	J.D. 241 +		h m
0	1901 Oct.	7	13	28	5665·561	5665·7220	(−3 52)
79	1903 Aug.	4	17	39	6331·735	6331·7394	− 6·3
80		13	4	13	6340·176	6340·1700	+ 8·6
81		21	14	20	6348·597	6348·6006	− 5·2
89	Oct.	28	0	53	6416·037	6416·0454	− 12·1
115	1904 June	3	5	44	6635·239	6635·2410	− 2·9
124	Aug.	18	3	17	6711·137	6711·1164	+ 29·7
173	1905 Oct.	5	5	05	7124 212	7124·2158	− 5·5
175		22	1	44	7141·072	7141·0770	− 7·2

The period of variation was then redetermined from the observed times of minimum, the finally adopted elements of variation (III.) being as under:

$$\begin{aligned}\text{Minimum} &= \text{1901 Oct. 7, } 17^{h}\ 20^{m}\ (\text{G.M.T.}) + 8^{d}\ 10^{h}\ 20^{m}\ 04^{s}\ E \\ &= \text{J.D. } 2415665{\cdot}722 + 8^{d}{\cdot}4306\ E\end{aligned}$$

There is no difference from the elements II. so far as the length of the period is concerned, and only a slight shift in the epoch of minimum. The computed times of minimum and the residuals O—C will be found in the table. The residuals seem to be quite satisfactorily small, considering the circumstances of the case.

The observation of 1901 October 7 is a photographic one. The star must have been at or very near its minimum brightness at the time of this photograph, but owing to the long duration of the stationary period this observation is of no use for correcting the elements, beyond showing that the period can hardly be any shorter than that adopted.

The normal brightness of the variable is 45·2 of the light scale = 9·93 mag., and the minimum brightness 6·5 = 11·87 mag. The duration of the stationary period is $7^{h}\ 0^{m}$, and the whole duration of the eclipse phase $20^{h}\ 30^{m}$. The long duration of the stationary period is somewhat interesting, and it would seem that one of the two component bodies is both larger and fainter than the other one. There is no indication of the existence of any secondary minimum.

Hove: 1905 *December* 26.

On a Method of Determining the Absolute Dimensions of an Algol Variable Star. By Alex. W. Roberts, D.Sc.

I. *Introduction.*

The present paper deals with an extension of the problem of Algol variation in the direction of a determination of the absolute dimensions of a close binary star.

Although the more definite and more accurate consideration of the dimensions of such systems falls more properly within the area of spectroscopic research, yet, theoretically at least, the light-curve of any eclipse variable exhibits data which when properly discussed yield a determination of the absolute size of the system.

The theory that underlies this important determination is the simple one that light takes an appreciable interval of time to traverse the orbit of a binary star.

A moment's reflexion will make it evident that this circumstance must make itself manifest as an acceleration in the apparent occurrence of both the primary and secondary maximum phases. The time of passing the primary and secondary maxima will, however, remain unchanged; that is, the approach and recession of the component stars relative to the Earth as they revolve round one another will be translated, owing to the measurable velocity of light, into a corresponding hastening and retardation of the successive phenomena of eclipse.

It will be clear, therefore, that if we had the means of ascertaining the light-curve of an Algol variable with perfect precision and completeness, and if all the phenomena of eclipse were capable of geometrical explanation and exposition, then, at all times, the light-curve of the system under consideration would provide sufficient data for a definite determination of the absolute dimensions—size, mass, and density of the eclipsing stars.

It will require little acquaintance with the many perplexities of variable star curves to assure one that, while in theory the problem of determining the dimensions of a binary star from an examination of its light changes has the merit of simplicity, in actual practice the solution is one beset with difficulties and obscured by uncertainties.

(1) It is not possible to determine the light-curve of a close binary star with the accuracy and refinement necessary for a numerical solution of the problem, except in cases where the variable completes its full period in a few hours.

In the latter circumstance the intervals between the four cardinal phases of variation, principal minimum, principal maximum, secondary minimum, secondary maximum, can be determined to within a minute of time. This is a quantity sufficiently refined to indicate, at least, a major limit to the size of the star.

(2) If all the phenomena of variation are to be included in a

consideration of the problem, and any system of exclusion must weaken the weight of the solution, then we must travel beyond the simple facts of eclipse to a region of physical causes and conditions to find a complete explanation of their origin and an interpretation of their character. We must, for instance, take into account the ever-changing figure of the component stars, due to eccentricity of orbit, as well as their rhythmic fluctuations in brightness, consequent on alterations in surface-pressure and tension.

(3) A number of untenable assumptions have always to to be made regarding the form and surface brightness of the component stars.

Notwithstanding these hindrances to a hopeful dealing with the question of the dimensions of an Algol variable, it seemed to me worth while instituting an inquiry as to the extent and nature of the uncertainty which must surround a solution so conditioned as that already indicated in the preceding paragraphs. I accordingly, early in 1905, worked out a graphical solution of the problem, taking the Lovedale observations of Algol variables as the materials of my investigation.

To my surprise the results obtained were much more definite than I had expected. They were, indeed, sufficiently final in character to convince me that in certain cases—*i.e.* rapidly varying stars—the problem admitted of a definite and reliable solution.

Lest my own observations, obtained by the method of sequences, might contain within them some systematic error leading to a false result, I asked Professor Pickering to permit me to make use of the very fine series of observations of the rapidly varying star *U Pegasi* made by Professor O. C. Wendell with the Harvard Meridian Photometer. With his usual kindness Professor Pickering at once sent me the whole of Professor Wendell's observations of *U Pegasi*.

I think it will be regarded as a sufficiently complete exposition of the problem we are considering if at this stage of its development we simply deal with two suitable stars, one in the northern hemisphere and one in the southern hemisphere.

The northern variable star *U Pegasi*, both because of its rapid period and because of the fulness and accuracy with which its light-curve has been determined by Professor Wendell, presents a very favourable object for the investigation we have in purpose.

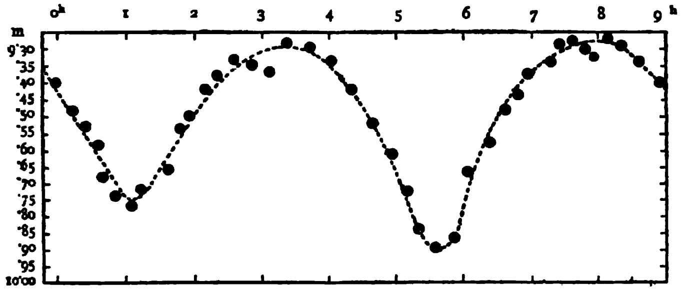
Then among southern stars over 10,000 observations have been secured of *RR Centauri*, the mean light-curve resulting from this mass of detail being sufficiently refined to warrant an inquiry regarding the absolute dimensions of the system.

The mode of observing both stars is so different in principle and in art that the possibility of a common systematic error, personal or instrumental, influencing the observations is remote.

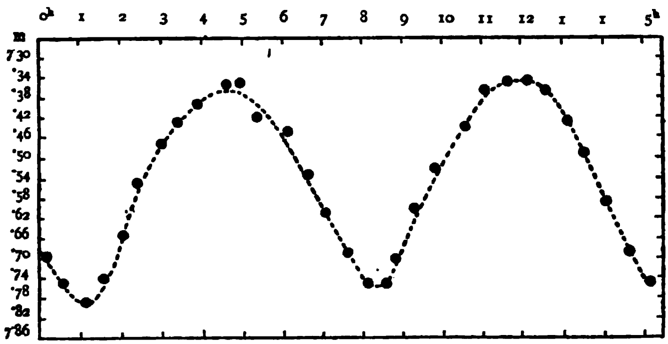
II. *Statement of the Problem.*

In the two following figures are given the light-curves of *U Pegasi* and *RR Centauri* respectively.

Before dealing directly with the relation which exists between the velocity of light and certain portions of the unsymmetric variation exhibited in these light-curves it will be necessary to distinguish and define, as far as we can, the more important circumstances which operate in producing the regular ebb and



Light Curve of *U Pegasi*. 1900 January 1.



Light Curve of *RR Centauri*. 1900 January 1.

flow of brightness represented in the light-curves under consideration, as well as in all light-curves of the same type.

(1) It seems reasonable to regard the major portion of the variation of both *U Pegasi* and *RR Centauri* as due to the eclipse of one star by its fellow.

If we consider the component bodies to move in a closed orbit, to be of regular and unchanging figure, then expressions may be readily deduced to exhibit the relation that exists between the symmetrical portion of an Algol star's variation and the chief elements of the system.

As the purpose of this paper is to deal with a wider extension of the problem than the simple determination of the elements of orbital movement, I may here just refer to the fact that a fairly full exposition of the relation connecting movement and variation is given in *Monthly Notices*, vol. lxiii. pp. 531–534. Those curious regarding the preliminary portion of the present investigation are referred to this article.

(2) The formulæ given in *Monthly Notices*, vol. lxiii. p. 534, presume that the eccentricity of the system is zero.

In order to correct any error arising from this assumption it is necessary to introduce into the equations defining the variation terms depending on the eccentricity.

Let

P = Period of variable in minutes.

ϵ = Eccentricity of orbit.

λ = Longitude of periastron reckoned from line of sight.

θ = True angular distance of eclipsing star from line of sight at time T.

Δm = Change in magnitude per minute at time T.

Then it is evident that

$$\frac{P \cdot \epsilon}{\pi} \sin(\theta+\lambda) \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

expresses the difference (in minutes) between the true anomaly and the mean anomaly at any time T if the eccentricity be small.

Consequently

$$\frac{\Delta m \,.\, P \cdot \epsilon}{\pi} \sin(\theta+\lambda) \ldots \quad \ldots \quad \ldots \quad (2)$$

is the correction in magnitude to be applied to the mean places, computed on the basis of a circular orbit, to reduce them to true places.

Putting

$$\epsilon \sin \lambda = p$$
$$\epsilon \cos \lambda = q$$

expression (2) becomes

$$\left(\frac{\Delta m \,.\, P}{\pi} \,.\, \cos\theta\right)p + \left(\frac{\Delta m \,.\, P}{\pi} \sin\theta\right)q \quad \ldots \quad \ldots \quad (3)$$

In the case therefore of the eccentricity and the position of the apsidal line being unknown, the above expression (3) will afford a means of determining their values.

(3) An examination of the light-curves of *U Pegasi* and *RR Centauri*, given above, indicates that eclipse alone will not account for all the phenomena of variation.

For example, we have distinct evidence in the case of both *U Pegasi* and *RR Centauri* of two unequal maxima.

This, as well as certain other irregularities, can be explained readily on the assumption that the eccentric movement of the component stars produces tidal perturbations, and consequent change of figure.

Physical movements of this nature must of necessity produce a measurable variation in the intrinsic brightness of the stars, as well as a definite and rhythmic alteration in their form.

If we regard these changes to be completed in the period of the star then a simple expression of the type

$$g \sin (\theta + Z)$$

may be taken as covering all the outstanding periodic variation due to physical causes.

Putting

$$g \sin Z = r$$
$$g \cos Z = s$$

this further correction becomes

$$r \cos \theta + s \sin \theta \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

(4) We still have the effect of the measurable velocity of light to consider. Theoretically this correction always remains to be made when the component stars of a binary system mutually eclipse one another. The correction admits of very simple exposition

Let

l = Time (in minutes) that light takes to cross the semi-orbit.

θ = Distance from line of sight.

Δm = Change in magnitude per minute.

Then correction for light equation becomes

$$\Delta m \,.\, l \,.\, \cos \theta \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

$\cos \theta$ being always positive.

This expression (5) gives the aberration in brightness in all Algol or eclipse light-curves, due to the apparent acceleration in time of the various phenomena of variation.

It is evident that if the amount of errancy be known, then the dimensions of the orbit are forthwith also known.

(5) It remains only to introduce a term, Δt, as a correction to the assumed time of passing the principal minimum phase.

If now we have computed the amount of symmetrical variation due to eclipse solely, it is clear that the residuals

$$(O - C)$$

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$$(O-C)$$

No.	Date.	Ref. Date H.M.T.	Magnitude.	No.	Date.	Ref. Date H.M.T.	Magnitude.
	1898.	1900.			1898.	1900.	
101	Dec. 28·596	Jan. 1·048	9·80	139	Jan. 1·630	Jan. 1·334	9·34
102	·600	·052	·79	140	·642	·346	·32
103	·607	·059	·77	141	·647	·351	·32
104	·613	·065	·77	142	·653	·357	·32
105	·618	·070	·67	143	1·658	·362	·28
106	·630	·082	·58	144	3·549	·005	·44
107	·635	·087	·50	145	·556	·012	·45
108	·640	·092	·44	146	·562	·018	·50
109	·644	·096	·44	147	·574	·030	·65
110	·648	·100	·44	148	·580	·036	·69
111	·665	·117	·36	149	·585	·041	·76
112	·669	·121	·39	150	·592	·048	·79
113	·676	·128	·37	151	·597	·053	·76
114	·681	·133	·40	152	·601	·057	·80
115	28·687	·139	·36	153	·619	·075	·64
116	30·608	·186	·44	154	·624	·080	·59
117	·612	·190	·47	155	·629	·085	·54
118	·618	·196	·50	156	·633	·089	·52
119	·628	·206	·60	157	·638	·094	·46
120	·635	·213	·64	158	·642	·098	·44
121	·644	·222	·86	159	·658	·114	·32
122	·655	·233	·90	160	·665	·121	·40
123	·662	·240	·96	161	3·671	·127	·30
124	Dec. 30·668	·246	·90	162	5·525	·106	·40
	1898.			163	·531	·112	·36
125	Jan. 1·531	·235	·94	164	·537	·118	·37
126	·537	·241	·88	165	·543	·124	·38
127	·544	·248	·82	166	·549	·130	·36
128	·551	·255	·73	167	·565	·146	·32
129	·558	·262	·62	168	·570	·151	·34
130	·571	·275	·48	169	·576	·156	·36
131	·575	·279	·44	170	·581	·162	·35
132	·580	·284	·46	171	·585	·166	·36
133	·585	·289	·40	172	·603	·184	·45
134	·591	·295	·42	173	·609	·190	·42
135	·598	·302	·37	174	·614	·195	·48
136	·603	·307	·32	175	·618	·199	·52
137	·622	·326	·28	176	·636	·217	·72
138	·626	·330	·31				

No.	Date. 1898.	Ref. Date H.M.T. 1900.	Magnitude.	No.	Date. 1898.	Ref. Date H.M.T. 1900.	Magnitude.
177	Jan. 5·642	Jan. 1·223	9·86	191	Jan. 7·523	Jan. 1·230	9·85
178	5·649	·230	·84	192	·538	·245	·87
179	7·442	·149	·35	193	·547	·254	·78
180	·450	·157	·35	194	·558	·265	·66
181	·457	·164	·31	195	·567	·274	·54
182	·462	·169	·32	196	·574	·281	·50
183	·469	·176	·36	197	·583	·290	·46
184	·476	·183	·42	198	·590	·297	·37
185	·485	·192	·46	199	·598	·306	·37
186	·490	·197	·50	200	·607	·314	·38
187	·494	·201	·52	201	·613	·320	·38
188	·501	·208	·59	202	·621	·328	·40
189	·508	·215	·67	203	·626	·333	·38
190	·513	·220	·80	204	7·633	1·340	9·35

We now proceed to obtain the mean light-curve of *U Pegasi* from the foregoing 204 observations.

In Table II. we have in detail the operation of finding the forty mean places set forth in Table III.

It will be observed that two observations are excluded—viz. Nos. 1 and 19. These are so manifestly out of accord with the other measures that no good purpose would be served by retaining them.

Also the following corrections for second differences have been allowed for :—

Number Table III.	Mean Date. d h m	Mean Magnitude.	Correction for Second Diff.	Corrected Magnitude.
6	Jan. 1 0 59	9·756	+0·002	9·758
7	1 11	·778	·004	·782
8	1 21	·736	·002	·738
25	5 28	·860	·004	·864
26	5 42	·906	·010	·916
27	1 5 55	9·878	+0·004	9·882

The mean magnitudes in Table III. are therefore corrected for second differences.

TABLE II.

Determination of Mean Places of U Pegasi.

Jan.	1·001	9·36
	·005	·45
	·005	·44
	·005	·42
	·006	·45
	·0044	·424
	·008	·58
	·012	·48
	·012	·45
	·012	·48
	·014	·53
	·0116	·504
	·018	·50
	·018	·49
	·019	·56
	·019	·58
	·024	·62
	·0196	·550
	·024	·50
	·024	·62
	·028	·62
	·030	·65
	·030	·66
	·0272	·610
	·031	·65
	(·032	·47)
	·034	·69
	·035	·69
	·036	·77
	·036	·69
	·0344	·698
	·039	·74
	·040	·82
	·041	·76
	·042	·74
	·043	·72
	·0410	·756

Jan.	1·048	9·79
	·048	·80
	·049	·71
	·051	·80
	·052	·79
	·0496	·778
	·053	·76
	·054	·72
	·057	·80
	·059	·77
	·060	·63
	·0566	·736
	·062	·70
	·065	·77
	·070	·67
	·070	·58
	·075	·64
	·0684	·672
	·075	·58
	·076	·58
	·080	·59
	·082	·58
	·082	·50
	·0790	·566
	·083	·57
	·085	·54
	·087	·50
	·088	·50
	·089	·52
	·0864	·526
	·092	·44
	·094	·46
	·095	·42
	·096	·44
	·098	·44
	·0950	·440

Jan.	1·099	9·50
	·100	·44
	(·100	·60)
	·101	·36
	·106	·40
	·107	·35
	·1026	·410
	·108	·36
	·112	·36
	·114	·32
	·117	·40
	·117	·36
	·1136	360
	·118	·37
	·121	·40
	·121	·39
	·124	·38
	·127	·30
	·1222	·368
	·128	·37
	·130	·44
	·130	·36
	·133	·40
	·139	·36
	·1320	·386
	·139	·36
	·144	·23
	·146	·32
	·149	·35
	·151	·34
	·1458	·320
	·156	·26
	·156	·36
	·157	·35
	·162	·35
	·164	·31
	·1590	·326

Jan. 1·166	9·36	Jan. 1·223	9·86	Jan. 1·283	9·48
·167	·33	·224	·85	·284	·46
·169	·32	·230	·84	·289	·45
·176	·36	·230	·85	·289	·40
·180	·48	·233	·90	·290	·46
·1716	·370	·2280	·860	·2870	·450
·183	·42	·235	·94	·291	·38
·184	·45	·235	·90	·294	·38
·186	·44	·235	·85	·295	·42
·187	·50	·240	·96	·297	·37
·190	·42	·241	·88	·299	·40
·1860	·446	·2372	·906	·2952	·390
·190	·47	·243	·94	·302	·37
·192	·50	·245	·87	·306	·37
·192	·46	·246	·90	·307	·34
·195	·48	·248	·82	·307	·32
·196	·50	·252	·86	·309	·33
·1930	·482	·2468	·878	·3062	·346
·196	·58	·254	·78	·310	·30
·197	·50	·255	·73	·313	·35
·199	·52	·258	·63	·314	·38
·201	·52	·262	·62	·318	·26
·202	·60	·262	·65	·319	·32
·1990	·544	·2582	·682	·3148	·322
·206	·60	·265	·64	·320	·30
·208	·59	·265	·66	·320	·38
·209	·70	·267	·58	·321	·30
·212	·65	·272	·51	·324	·29
·213	·64	·273	·54	·325	·28
·2096	·636	·2684	·586	·3220	·310
·216	·67	·274	·54	·325	·25
·217	·76	275	·48	·326	·28
·217	·72	·279	·44	·328	·40
·220	·80	·281	·50	·330	·31
·222	·86	·282	·50	·331	·37
·2184	·762	·2782	·492	·3280	·322

Jan. 1·331	9·22	Jan. 1·350	9·30
·333	·38	·351	·24
·333	·38	·351	·32
·334	·34	·355	·38
·340	·35	·355	·34
		·357	·32
·3342	·334	·3532	·317
·340	·20	·362	·28
·343	·32	·362	·37
·345	·32	·362	·38
·346	·32	·365	·40
·350	·30	·367	·36
		1·371	9·40
·3448	·292	1·3648	9·365

TABLE III.

Mean Light-curve of U Pegasi.

No.	Date.		Observed Mag.	Computed Mag.	(O–C.)
	1900. d	1900. d h m	m	m	m
1	Jan. 1·0044	Jan. 1 0 6	9·424	9·447	–0·023
2	·0116	0 17	·504	·500	+ ·004
3	·0196	0 28	·550	·562	– ·012
4	·0272	0 39	·610	·633	– ·023
5	·0344	0 50	·698	·704	– ·006
6	·0410	0 59	·758	·756	+ ·002
7	·0496	1 11	·782	·782	·000
8	·0566	1 21	·738	·764	– ·026
9	·0684	1 39	·672	·660	+ ·012
10	·0790	1 54	·566	·562	+ ·004
11	·0864	2 5	·526	·500	+ ·026
12	·0950	2 17	·440	·443	– ·003
13	·1026	2 28	·410	·400	+ ·010
14	·1136	2 44	·360	·358	+ ·002
15	·1222	2 56	·368	·337	+ ·031
16	·1320	3 10	·386	·323	+ ·063
17	·1458	3 30	·320	·320	·000
18	·1590	3 49	·326	·330	– ·004
19	·1716	4 7	·370	·361	+ ·009
20	·1860	4 28	·446	·431	+ ·015
21	·1930	4 38	·482	·481	+ ·001

No.	Date. 1900. d.	1900. d h m	Observed Mag. m	Computed Mag. m	(O−C.) m
22	Jan. 1·1990	Jan. 1 4 47	9·544	9·538	+0·006
23	·2096	5 2	·636	·650	− ·014
24	·2184	5 15	·762	·767	− ·005
25	·2280	5 28	·864	·874	− ·010
26	·2372	5 42	·916	·924	− ·008
27	·2468	5 55	·882	867	+ ·015
28	·2582	6 12	·682	·721	− ·039
29	·2684	6 27	·586	·595	− ·009
30	·2782	6 41	·492	·498	− ·006
31	·2870	6 53	·450	·435	+ ·015
32	·2952	7 5	·390	·390	·000
33	·3062	7 21	·346	·347	− ·001
34	·3148	7 33	·322	·330	− ·008
35	·3220	7 44	·310	·321	− ·011
36	·3280	7 52	·322	.320	+ ·002
37	·3342	8 1	·334	·320	+ ·014
38	·3448	8 17	·292	·327	− ·035
39	·3532	8 29	·317	·342	− ·025
40	1·3648	1 8 45	9·365	9·375	−0·010

Dealing with the foregoing mean magnitudes in the manner indicated in my paper on the orbit of *RR Centauri* (*Monthly Notices*, 1903 June), we obtain the following elements :

Period of *U Pegasi*	$8^h\ 59^m\ 41^s{\cdot}34$
Epoch of minimum	1900 Jan. $1^d\ 1^h\ 11^m$
Inclination of orbit	15° 20′
Prolateness of stars	0·46
Brightness of $\text{star}_{(1)}$	0·57
Brightness of $\text{star}_{(2)}$	0·43

The components are considered to be equal in size, and to revolve round one another, in contact, in a circular orbit.

Computed magnitudes based on the foregoing group of elements are given in col. 5 of Table III., and the residuals in the last column of the same table.

Now, as already stated, it is evident that (1) if the orbit of *U Pegasi* be eccentric, (2) if there be a rhythmic and physical fluctuation in brightness due to tidal deformation, and (3) if the acceleration of the two minima, due to the light-equation, be sufficiently great to be discernible, then the computed magnitudes require a further correction for these secondary causes of variation,

and the (O−C) quantities of col. 6, Table III., yield data for determining the value and extent of these corrections.

Equation (6) expresses the relation which may reasonably be held to exist between the secondary causes of variation and the outstanding unsymmetrical portion of the light changes.

Recasting equation (6), so as to render it more uniform and serviceable, we may write it thus:

$$(10{,}000\ \Delta m \cos\theta)\frac{Pp}{10\pi}+(10{,}000\ \Delta m \sin\theta)\frac{Pq}{10\pi}$$

$$+(100\cos\theta)\,10r+(100\sin\theta)\,10s$$

$$+(10{,}000\ \Delta m\cos\theta)\frac{l}{10}+(10{,}000\ \Delta m)\frac{\Delta t}{10}=1000\,(O-C)\quad\ldots\ (7)$$

We can now from Table III. readily form a system of equations of condition which determine (1) the amount of eccentricity of orbit, (2) any intrinsic changes in the brightness of the system, and (3) the absolute dimensions of the system.

System of Equations of Condition.

$$+31\left(\frac{Pp}{10\pi}\right)-29\left(\frac{Pq}{10\pi}\right)+73(10r)-68(10s)+31\left(\frac{l}{10}\right)+43\left(\frac{\Delta t}{10}\right)=-23$$

42	31	81	59	42	52	+ 4
53	29	88	48	53	60	−12
62	24	93	36	62	67	−23
58	15	97	25	58	60	− 6
+47	7	99	−14	+47	+47	+ 2
00	0	100	0	0	0	0
−33	4	99	+12	−33	−33	−26
63	21	95	31	63	66	+12
53	29	88	48	53	60	+ 4
42	30	81	58	42	52	+26
32	30	72	69	32	44	− 3
21	26	63	78	21	33	+10
10	18	47	88	10	20	+ 2
4	12	34	94	4	13	+31
1	− 6	+19	98	− 1	− 6	+63
0	0	− 5	100	0	0	0
3	+10	26	97	+ 3	+10	− 4
11	21	46	89	11	23	+ 9
24	27	66	75	24	36	+15
−39	+36	−74	+67	+39	+53	=+ 1

$+31\left(\frac{Pp}{10\pi}\right)$	$-29\left(\frac{Pq}{10\pi}\right)$	$+73(10r)$	$-68(10s)$	$+31\left(\frac{l}{10}\right)$	$+43\left(\frac{\Delta t}{10}\right)$	$=-23$
56	42	80	59	56	70	+ 6
75	37	90	44	75	83	−14
83	27	95	31	83	87	− 5
−65	10	99	+15	+65	+66	−10
+10	0	100	0	−10	−10	− 8
75	12	99	−16	75	76	+15
87	33	94	35	87	93	−39
63	37	86	50	63	73	− 9
46	38	77	64	46	60	− 6
31	34	67	74	31	46	+15
19	28	56	83	19	33	0
8	19	39	92	8	20	− 1
3	10	26	97	3	10	− 8
1	+ 6	14	99	− 1	− 6	−11
0	0	− 4	100	0	0	+ 2
0	0	+ 6	100	0	0	+14
2	−10	24	97	+ 2	+10	−35
8	19	37	93	8	20	−25
+20	−30	+54	−84	+20	+36	=−10

The normal equations resulting from the foregoing system of forty equations of condition are :

$69509\left(\frac{Pp}{10\pi}\right)$						
	$-2334\left(\frac{Pq}{10\pi}\right)$	$+\ 7710(10r)$	$-57844(10s)$	$-16241\left(\frac{l}{10}\right)$	$-17959\left(\frac{\Delta t}{10}\right)$	$=-11202$
	21911	−57014	− 1120	− 920	− 1411	− 570
		106371	+ 1570	+ 4730	+ 5220	+ 900
			193605	+ 4662	+ 5431	+22275
				69509	+78719	− 3370
					91269	=− 5020

which yield

$$\frac{Pp}{10\pi} = -0{\cdot}107$$

$$\frac{Pq}{10\pi} = +0{\cdot}000$$

$$10r = +0{\cdot}018$$

$$10s = +0{\cdot}085$$
$$\frac{l}{10} = +0{\cdot}585$$
$$\frac{\Delta t}{10} = -0{\cdot}587$$

From which, since

$$\frac{P}{10\pi} = 172$$
$$p = \epsilon \sin \lambda$$
$$q = \epsilon \cos \lambda$$
$$r = g \sin Z$$
$$s = g \cos Z$$

it follows that

$$\epsilon = 0{\cdot}006$$
$$\lambda = 270^\circ$$
$$g = {\cdot}009$$
$$Z = 12^\circ$$
$$\Delta t = -5^{m}{\cdot}9$$
$$l = +5^{m}{\cdot}9$$

The purpose of the present paper is fulfilled in dealing only with the last of the foregoing values, viz.

$$l = 5^{m}{\cdot}9.$$

This represents the time light takes to cross the semi-orbit of *U Pegasi*.

Reducing the value to miles we obtain as the distance of the component stars that go to form the system *U Pegasi*

63,240,000 miles

As observations of *U Pegasi* multiply, and a more and more accurate mean light-curve is the result, this quantity may be corrected to no inconsiderable extent.

I think, however, the present investigation has demonstrated the possibility of obtaining the absolute dimensions of a rapidly varying binary star. This in itself is a matter of some importance.

IV. *Size of RR Centauri.*

In the *Monthly Notices*, vol. lxiii. pp. 538, 539, we find twenty-nine mean magnitudes of this star, as also the corresponding computed magnitudes, derived in the ordinary way from a system of orbital elements. We may treat the

residuals in the last column of the paper referred to in the same manner as we have done the residuals of *U Pegasi*. That is, we may endeavour to discover what portion of the outstanding residuals is due to (1) eccentricity of orbit, (2) intrinsic changes in the surface brightness of the component stars, (3) light-equation.

Taking, therefore, as our type of equation of condition expression (7) in the preceding part of this discussion, we may readily form the following system :

Equations of Condition.

$$+29\left(\frac{Pp}{10\pi}\right)-13\left(\frac{Pq}{10}\right)+92\,(10r)-39(10e)+29\left(\frac{l}{10}\right)+32\left(\frac{\Delta t}{10}\right)=+10$$

+20	4	98	−19	+20	20	− 7
− 6	0	100	+ 4	− 6	6	+ 6
24	6	97	24	24	25	0
29	14	90	43	29	32	− 9
25	19	79	61	25	31	−16
17	20	64	77	17	26	− 8
8	15	45	89	8	17	+18
3	10	25	97	− 3	10	+17
0	− 2	+ 2	100	0	− 2	− 6
1	+ 7	−16	99	+ 1	+ 7	−12
6	14	40	92	6	15	+22
13	19	58	82	13	23	− 1
21	18	75	86	21	28	+ 3
26	15	87	50	26	30	− 1
22	7	96	29	22	23	−13
− 5	0	100	+ 7	+ 5	+ 5	− 5
+17	2	99	−14	−17	−17	+ 6
25	8	95	30	25	26	+ 2
26	16	85	53	26	30	0
20	19	73	69	20	28	+ 3
11	18	54	84	11	21	+ 3
4	11	34	94	4	12	−15
1	+ 6	−15	99	− 1	− 6	−11
0	− 3	+ 8	100	0	+ 3	− 7
3	10	29	96	+3	11	− 8
9	17	48	88	9	19	+ 8
17	20	65	76	17	26	+ 6
+16	−19	+81	−58	+26	+32	= + 7

M

Normal equations

$$8696\left(\frac{Pp}{10\pi}\right)-59\left(\frac{Pq}{10\pi}\right)-1692(10r)-21330(10s)+776\left(\frac{l}{10}\right)+894\left(\frac{\Delta t}{10}\right)=+1$$

5036	−21351	+ 124	+ 23	+ 0	—
	145870	+ 270	+ 336	+ 319	+ 1
		144555	−864	− 1019	+ 2
			8690	+ 10612	+
				13641	= +

which yield

$$\frac{Pp}{10\pi}=+0{\cdot}316$$
$$\frac{Pq}{10\pi}=+0{\cdot}016$$
$$10r=+0{\cdot}013$$
$$10s=+0{\cdot}065$$
$$\frac{l}{10}=+0{\cdot}029$$
$$\frac{\Delta t}{10}=+0{\cdot}034$$

From which since

$$\frac{P}{10\pi}=278$$
$$p=\epsilon\sin\lambda$$
$$q=\epsilon\cos\lambda$$
$$r=g\sin Z$$
$$s=g\cos Z$$

it follows that

$$\epsilon=0{\cdot}012$$
$$\lambda=90^\circ$$
$$g=0{\cdot}006$$
$$Z=12^\circ$$
$$\Delta t=+0^{m}{\cdot}3$$
$$l=+0^{m}{\cdot}3$$

Dealing again only with the quantity

$$l=+0^{m}{\cdot}3$$

we obtain as the semi-orbit of *RR Centauri*

3,800,000 miles

I may mention that I have instituted a series of observations of this star with the express purpose of securing as accurate a determination as possible of the four cardinal points of variation.

As the orbit of the star has been demonstrated to be practically circular, the four dates—principal minimum, principal maximum, secondary minimum, secondary maximum—will yield accurate values of the dimensions of the system, inasmuch as—

(Duration of first quadrant + duration of third quadrant)
—(Duration of second quadrant + duration of fourth quadrant)
= four times the light-equation of the radius of the orbit.

Micrometrical Measures of Double Stars. (Third Series.)
By Rev. T. E. Espin.

The following list completes the measures obtained up to the end of 1905. The stars are all situated between +30° and +40°. Attention has mostly been given to stars neglected hitherto, and a large number of the stars noted as double in the Catalogues of the Astron. Gesellschaft were put on the working list. Subsequently Professor Burnham informed me that these are already sufficiently well cared for, and so only measures were continued where they had been already commenced.

Stars of Σ and OΣΣ.

No.	R.A. 1900 h m	Dec. ° ′	P. °	D. ″	Mags.		Nights.	Date.
OΣΣ 2 ...	0 26·2	+33 1	85·3	55·67			2	04·81
Σ 40 ...	29·8	36 16	315·1	11·29	7·1	8·4	3	04·86
OΣΣ 4 ...	31·5	33 10	173·9	36·11			1	04·80
Σ 62 ...	44·8	35 13	304·8	11·38	8·8	9·0	3	04·88
OΣΣ 11 ...	1 1·6	38 7	159·7	62·77	7·0	8·0	1	04·87
Σ 179 ...	47·3	36 50	159·1	3·29			3	05·88
Σ 434 ...	3 37·4	38 4	85·1	30·38	7·0	7·1	2	05·08
Σ 447 ...	41·4	38 3	167·6	27·39	7·0	9·2	2	05·08
Σ 1688 ...	12 48·8	38 31	343·9	14·08	...	...	2	05·29
Σ 1692 ...	51·4	38 51	228·0	19·81	...	...	3	05·31
Σ 1702 ...	53·9	38 50	83·0	35·23	...	...	2	05·29
OΣΣ 125...	13 42·7	39 2	237·5	71·08	5·0	8·5	2	05·39
Σ 1965 ...	15 35·6	36 58	303·1	6·37			2	05·38
Σ 1973 ...	42·7	36 45	322·6	30·44			2	05·38
Σ 2610 ..	14 55·4	+35 16	294·9 / 203·3	3·84 / 12·01	8·0	8·1 / 11·5	3	05·87

No.		R.A. 1900 h	m	Dec. °	′	P. °	D. ″	Mags.		Nights.	Date.
Σ 2876	...	22	7·7	+37	9	67·5	11·68	...	...	4	04·91
Σ 2882	...		9·9	37	15	326·4	3·07	9·0	9·1	3	04·90
Σ 2894	...		14·5	37	16	193·9	15·38	6·5	8·0	2	04·89
OΣΣ 243	...	23	5·4	36	19	319·1	66·98	6·5	7·0	2	04·78
Σ 3028	...		33·6	34	29	201·9	17·13	6·5	9 5	2	05·05
Σ 3050	...		54·4	+33	10	216·4	2·61	...	...	2	05·05

h's Stars.

No.		R.A. 1900 h	m	Dec. °	′	P. °	D. ″	Mags.		Nights.	Date.
h 624	...	0	23·8	+33	20	347·0	15·28	8·9	11·2	2	05 40
h 636	...	1	8·8	30	0	287·5	20·08	7·2	11·0	2	04·78
h 1081	...		24·3	41	0	317·3	9·35	9·0	9·3	2	04·86
h 1087	...		31·4	38	31	73 5	11·37	9·0	10·0	3	04·83
h 645	...		46·8	30	58	103·5	7·54	8·0	10·5	2	04·78
h 1097	...		50·2	37	15	39·2	14 45	9·5	11·0	3	05·20
h 1120	...	2	29·2	39	13	90·9	17·32	7·0	11·5	2	05·94
h 654	...		38·0	34	42	44·6	36·76	7·5	11·0	2	04·82
h 669	...	3	48 1	35	1	262·6	12·04	9·0	9·2	1	04·87
h 496	...	11	16·1	37	21	328·9	28·28	9·0	9·8	2	05·24
h 519	...	12	25·5	36	41	4·7	19·84	9·1	9·3	2	05·29
h 554	...	14	28·3	35	11	294·4	12·05	9·2	9·5	2	05·38 AB
h 562	...		55·7	35	30	309·7	24·36	7·5	11·5	2	05·38 (Σ 1900 rej.)
h 565	...	15	0·0	33	57	104·6	33·19	8·1	10·5	2	05·38
h 566	...		5·1	33	26	286·0	23·89	8·4	9·9	2	05·41 (Σ 1913 rej.)
h 2786	...		29·6	38	46	166·8	24·53	8·1	11·5	2	05·38
h 1349	...	18	45·1	33	12	81·0	22·08	8·0	11·6	2	04·71
h 1414	...	19	29 1	35	54	24·8	15·47	8·8	10·0	3	04·65
h 1447	...		47·9	33	49	333·9	18·95	7·5	11·8	3	04·61 AB
						85·6	22·30	C = 13·2		3	05·04 AC
h 1449	...		49·2	32	47	284·0	7·80	9·0	12 2	2	04·72
h 1471	...	20	0·7	31	55	4·4	29·18	5·9	11·5	3	04·63
h 1523	...		25·5	40	40	349·4	14·07	9·0	9·4	2	04·77 *h* 357°·4
h 1526	...		26·8	35	1	329·6	8·72	8·8	8·9	3	04·74
h 1535	...		29·3	33	2	246·3	15·86	8·0	13·5	2	05·91 A*a*(new)
						151·0	17·47	...	13·0	2	05·91 AB
						232·2	34·28	...	11·0	2	05·91 AC
h 609	...		29·5	40	12	327·1	25·73	8·7	8·9	2	04·71
h 612	...		37·3	38	44	8·8	47·97	6·5	11·5	3	04·71
h 1560	...		37·9	+35	33	246·2	11·13	9·0	11·5	2	05·93 AB
						74·3	24·98	...	13·0	2	05·93 AC

No.		R.A. 1900 Dec. h m	° ′	P. °	D. ″	Mags.		Nights.	Date.
h 1568	...	0 39·0	+35 34	43·8	11·19	8·7	11·5	2	05·93
h 1582	...	45·9	38 9	45·0	17·13	7·8	13·0	2	05·89 AB(new)
				327·4	27·22	...	11·0	3	05·92 AC
h 1586	...	48·3	35 21	260·9	15·62	7·8	12·7	2	04·71
h 1596	...	51·8	33 39	295·5	16·86	8·9	11·2	3	04·68 h 258°·6
h 1664	...	21 31·7	32 52	88·1	7·68	9·7	9·7	2	05·30
h 953	...	22 0·1	32 27	104·4	21·14	6·8	12·5	2	04·66
h 1756	...	17·5	40 10	286·8	21·54	7·0	11·7	3	04·76
h 965	...	24·6	34 0	140·8	29·78	8·4	9·2	3	04·74
h 1779	...	28·0	33 42	217·2	21·31	7·8	9·2	2	04·69 h 244°·9
h 1788	...	30·5	41 3	298·9	3·71	8·7	9·2	2	04·71
h 968	...	35·0	36 22	109·1	4·42	8·3	8·8	3	04·74
h 969	...	41·3	33 27	24·8	5·98	...	...	3	04·78
h 1813	...	44·1	41 4	61·6	9·36	8·9	9·0	2	04·98
h 1817	..	46·1	33 56	239·5	10·46	9·0	9·4	2	04·74 h 247°·5
h 1832	...	52·6	38 8	73·8	10·97	8·8	9·2	2	04·68
h 983	...	23 9·9	31 14	157·7	16·41	8·8	9·5	2	04·81
h 1882	..	22·9	38 51	323·4	13·00	9·0	13·0	3	05·95 h 306°·0
h 987	...	24·7	+31 40	280·5	12·62	8·8	11·7	2	05·93

Various Stars.

Σ 3064 rej.		0 3·2	+39 32	357·5	23·92	6·8	9·6	2	04·72
Hh 6	...	14·8	37 41	18·6	70·39	6·5	8·9	3	04·82
A.G.C.	...	1 9·0	40 30	43·2	6·62	8·8	10·0	2	04·86
Σ 181 rej.	...	48·7	37 42	124·8	26·53	8·5	9·2	2	04·86
A.G.C.	...	50·3	35 33	70·1	5·24	8·7	8·9	2	04·80
Ho. 10	...	52·9	37 11	193·1	2·66	8·0	11·0	6	05·86
Σ 210 rej.	...	59·7	36 28	242·8	16·82	8·6	9·5	2	05·91
A.G.C.	...	2 34·8	34 24	288·1	9·96	9·0	9·2	1	04·87
A.G.C.	...	3 7·4	37 9	128·1	5·28	9·0	9·3	2	05·44
A.G.C.	...	9·1	38 18	246·0	9·46	8·5	8·8	1	05·77
Σ 1382 rej.		9 43·1	34 33	106·8	27·89	6·5	11·0	3	05·25
Holmes	..	17 52·1	39 31	99·7	5·30	8·6	9·2	2	04·61
Σ 2386 rej.		18 41·7	35 26	18·1	20·43	8·7	9·2	2	04·60
Hh 583	...	46·2	32 41	73·2	36·71	5·5	13·0	2	04·84 (new) AB
				121·7	58·91	C=9·5		3	04·83 AC
A.G.C.	...	19 1·9	37 53	4·0	5·58	8·7	9·1	3	04·65
Hh 608	...	12·9	37 57	71·0	100·14	...	...	2	04·81 θ Lyræ
A.G.C.	...	31·0	35 5	278·9	11·42	9·0	9·8	3	04·76
A.G.C.	..	32·4	+36 4	332·3	2·99	9·0	9·4	3	04·65

No.	R.A. 1900		Dec.		P.	D.	Mags.		Nights.	Date.
	h	m	°	′	°	″				
A.G.C. ...	0	39·5	+31	43	168·0	11·11	8·5	9·5	2	04·81
A.G.C. ...		39·7	34	36	158·3	5·29	9·1	9·3	3	04·75
A G.C. ...		57·9	31	22	354·7	12·81	8·7	9·1	2	04·84
Espin 202 ..		58·6	35	2	221·8	10·92	8·8	13·0	2	05·63 A*a*
Σ 2638 rej.	20	5·3	33	22	74·7	16·67	8·0	9·1	2	04·71
Aitken 281		6·8	34	34	169·3	3·87	8·6	8·7	2	04·94
A.G.C. ...		15·6	36	16	117·6	9·48	8·7	8·9	2	04·68
A.G.C. ...		20·5	31	53	342·6	5·51	8·0	8·6	2	04·67
A.G.C. ...		22·5	37	8	287·8	5·24	9·0	9·2	3	04·74
A.G.C. ...		25·5	37	11	210·9	3·76	7·5	8·3	6	04·83 AB
					200·7	11·65	9·0	10·7	2	04·90 CD
					99·9	87·97	...	...	2	04·90 AC
A.G.C. ...		30·3	40	12	267·3	9·26	8·5	8·8	2	04·71
A.G.C. ...		34·5	30	47	153·6	3·74	8·0	9·0	2	05·38
A.G.C. ...		41·8	36	25	205·4	6·26	8·9	8·9	2	04·74
A.G.C. ...		42·9	32	30	86·7	10·89	7·8	8·5	1	04·82
A.G.C. ...		56·4	33	47	30·4	6·68	8·0	10·0	2	04·83
A.G.C. ...	21	4·4	40	30	107·1	5·33	8·9	9·2	3	04·68
A.G.C. ...		15·0	38	44	114·1	5·77	...	...	2	04·68
S 799 ...		39·3	37	49	60·0	152·74	...	...	1	05·90 AB
					248·5	30·76	C = 14·0		2	05·93 BC (new)
A.G.C. ...	22	5·9	31	11	178·4	10·15	9·0	10·0	3	04·56
Espin 216...		33·3	36	9	0·4	2·32	9·5	11·0	3	05·87 BC
					39·4	45·07	A = 8·5		1	05·75 AB
H*h* 771 ...		34·8	38	32	48·6	61·23	4·7	9·6	2	04·64
H*h* 772 ...		37·0	39	42	15·9	69·32	...	...	2	04·68
A.G.C. ...		40·7	39	30	192·2	14·14	9·0	10·5	2	04·76
Espin 217...		40·9	36	23	61·5	3·11	10·7	11·4	3	05·86
					295·1	74·16	A = 8·3		2	05·81
Hu. 782 ...		40·9	33	28	322·4	1·95	9·7	10·2	2	04·79
A.G.C. ...	23	20·7	32	53	230·5	3·05	8·8	10·2	3	04·78
Sh. 348 ...		49·9	31	17	329·0	36·98	8·0	9·5	2	04·70
A.G.C. ...		50·6	37	56	53·4	5·03	9·1	9·2	2	04·71
A.G.C ...		52·1	+37	17	316·6	1·98	9·2	9·3	4	04·74

Notes.

h 1097. *h*'s place agrees with B.D. + 37°·416, and this has been accordingly measured. *h*'s description is: "In Cluster VII. 32; no particulars."

h 1120. *h*'s angle 100°·0. *h* gives a third star, 320° ± 25″, which was seen on each night, but not measured.

h 654. B.D. + 34° 504 taken, from which *h*'s place differs by $-1^{m}\,9^{s}$ in R.A.

h 1526. 1904 October 24 suspected A double. This is Ho. 760, who reverses the angle of AB, and had found the close pair earlier in the year.

h 1535. *h* gives AB 108° ± AC 240°·3. The great difference in *h*'s position and the nearer *comes* led me to suspect at first that he had observed some other star. Subsequently it seemed probable that the difference in position might be explained by giving A a P.M. of 0″·163 towards 38°·0. The faint *comes* "*a*" would then have been distant about 7″ at the time of *h*'s observation, and might easily be overlooked. Professor Bakhuyzen informs me that the results of the Leiden meridian observations show that A has a P.M. of 0″·168 towards 47° 30′. This would make "*a*" even closer at the time of *h*'s measures.

Various Stars.

H*h* 6. A star with large proper motion—according to Porter, 0″·314 at 202°·3.

Ho. 10. This is a difficult star to measure, but there is possibly some motion:

Ho. 1884·56	P = 198°·5	D = 2″·50
Ho. 1893·86	196·6	2·58

Σ 1382 rej. Four *comites*, according to *h*. A 13·5 mag., P about the same distance as AB.

Hu. 782. Found and measured before Professor Hussey's results reached me.

Sh. 358. No alteration since β's measures. Washburn Obs., vol. i., p. 157.

New Double Stars. By Rev. T. E. Espin.

No.	B.D.	R.A. 1900 h m	Dec. ° ′	P. °	D. ″	Mags.		Nights.	Date.	
222	+38°46	0 20·6	+38 14	152·5	5·30	8·6	9·5	2	05·89	
223	...	41·5	38 15	262·5	3·82	9·5	9·5	3	05·83	
224	37·130	41·8	38 5	344·8	10·56	8·6	13·7	2	05·86	
225	37·138	42·8	38 6	250·9	6·49	9·0	14	2	05·86	
226	38·144	49·9	38 27	282·4	6·10	9·0	12·5	2	05·79	
227	34·293	1 34·6	34 17	78·1	3·76	9·3	9·8	2	05·90	
228	...	51·0	37 30	9·5	3·51	9·7	9·7	3	05·79	
229	37·497	2 5·2	37 37	38·2	1·67	9·0	10·5	4	05·87	
230	...	8·2	37 40	301·6	2·86	9·3	9·9	4	05·87	
231	37·606	35·6	37 59	81·1	3·95	8·7	9·5	2	05·83	
232	39·654	46·6	39 29	188·8	2·30	8·7	9·6	2	05·94	
233	34·722	3 37·4	35 0	80 ±	4 ±	8·6	12·0		05·87	
234	33·710	39·0	33 34	*f*	5 ±	9·3	12·0		05·89	
235	34·732	41·4	34 44	271·3	2·5	12·0	12·0	1	05·89	BC
				227·1	35·01	A =	8·7	2	05·88	AB
236	34·744	44·0	34 22	352·8	4·96	9·3	9·6	3	05·90	
237	33·757	54·6	33 58	117·8	6·65	9·0	10·0	2	05·88	
238	34·809	59·4	34 22	*sf*	2 ±	9·3	9·5		05·94	

No.	B.D.	R.A. 1900		Dec.		P.	D.	Mags.		Nights.	Date.	
	°	h	m	°	′	°	″					
239	35·856	4	16·5	35	59	...	4 ±	9·0	12·0		05·87	
240	39·1083		44·0	39	18	...	5 ±	9·5	11·0		05·79	
241	36·3293	18	48·0	36	41	69·8	2·03	9·1	10·7	2	05·71	
242	36·3730	19	46·4	36	28	22·1	2·22	9·5	10·0	2	05·85	
243	34·3844		58·2	35	6	294·7	4·78	9·0	10·2	3	05·71	
244	34·3934	20	10·6	35	7	129·6	40·72	7·5	11·5	2	05·69	AB
						14·1	5·00	C =	12·0	2	05·69	BC
						306·0	4·74	D =	13·2	2	05·69	CD
245	39·5215		26·5	39	47	160·3	4·76	9·4	9·5	2	05·79	
246	38·4133		27·9	38	11	8·2	6·21	9·0	11·5	3	05·75	AB
						355·4	10·93		10·5	2	05·72	AC
247	36·41.6		32·6	36	30	147·9	5·49	8·8	10·2	2	05·82	
248	36·4173		36·1	36	42	2·0	5·50	9·0	13·0	3	05·94	
								(*comes* 14″·7 *nf*)				
249	33·4031		44·0	34	2	22·3	5·41	9·0	10·0	2	05·80	
250	36·4287		48·2	36	22	87·6	4·26	9·2	12·5	3	05·86	
251	36·4352		54·8	36	21	142·9	6·32	8·7	9·3	2	05·88	
252	36·4442	21	6·2	37	0	170·2	3·49	8·7	9·5	2	05·75	
253	37·4207		6·7	37	12	22·3	3·46	8·9	9·6	2	05·75	
254	37·4210		7·0	38	4	330·3	2·39	8·8	9·1	2	05·75	
255	39·4473		7·1	40	7	33·0	4·89	8·9	11·7	3	05·84	
256	39·4481		9·0	40	7	280·5	4·34	9·5	9·7	3	05·84	
257	38·4397		9·1	38	32	323·1	5·80	8·0	12·0	2	05·91	
258	35·4543		25·5	35	59	355·3	4·02	9·3	12·0	3	05·87	BC
						203·3	25·41	A =	9·0	1	05·83	AB
259	38·4522		28·2	38	22	321·9	2·80	9·2	9·5	2	05·93	
260	38·4525		28·5	38	35	280·8	5·63	9·0	13·0	2	05·85	
261	39·4695		48·2	39	52	162·5	4·67	9·2	9·2	1	05·96	
262	36·4[illegible]84	22	32·4	37	9	162·2	5·16	8·7	10·5	2	05·78	
263	40·4860		32·4	40	38	245·8	9·30	8·9	14·0	3	05·84	
264	40·4862		33·0	40	30	356·4	8·54	8·6	12·5	3	05·84	
265	32·4501		39·3	33	6	1·4	8·49	8·8	9·3	3	05·93	
266	39·4958		48·8	39	48	84·8	13·75	8·0	10·7	2	05·86	
267	..	23	25·8	38	57	174·0	2·21	9·6	11·0	2	05·86	
268	39·5161		41·9	39	59	266·3	4·23	8·5	10·0	2	05·79	
...	40·5150		43·1	40	33	215·5	26·78	7·9	8·4	2	05·94	
269	40·5153		44·0	40	46	216·3	6·64	8·8	11·0	2	05·79	
						139·8	15·42	C =	13	2	05·79	
...	40·5167		48·0	40	48	145·4	50·98	6·5	8·8	2	05·94	

Notes.

224. Discordant angles.

225. Measures somewhat discordant, very difficult.

226. The same remarks apply to this star.

244. CD. The measures are little more than estimations.

248. Measures of angle discordant, the 14-mag. *comes* noted only on October 31.

260, 267. Measures discordant.

B.D. + 40°·5150. A fine wide pair, not given in any catalogue of double stars so far as I am aware.

B.D. + 40°·5167. Marked double in Argelander: A orange, B contrasted blue.

Erratum.

In the Greenwich Double Star measures given in the November number of the *Monthly Notices* (vol. lxvi. No. 1) the date at the head of the "Epoch" column on pp. 20–32 should be 1904.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

Vol. LXVI. February 9, 1906. No. 4

ANNUAL GENERAL MEETING.

Mr. W. H. Maw, President, in the Chair.

The Report of the Auditors of the Treasurer's accounts for the year 1905 was read; see p. 154.

The Address was delivered by the President, after which the Gold Medal was handed to His Excellency the American Ambassador for transmission to Professor W. W. Campbell, to whom the Medal had been awarded for his spectroscopic researches, which have greatly increased our knowledge of Stellar Motions (see pp. 245 to 261).

The Annual Report of the Council was partly read; see pp. 151 to 244.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 261.

The thanks of the Meeting were given to the retiring Officers, and also to the Auditors of the Treasurer's Accounts and to the Scrutineers of the ballot.

Robert Courtenay, B.A. (T.C.D.), 34 Wilmount Street, Woolwich;
Lieut. Chetwode G. G. Crawley, R.M. Artillery, B.A. (T.C.D.), H.M.S. "Vernon," Portsmouth; and
John Milne Gardiner Shaw, M.Inst. Naval Architects, F.R.Met.Soc., c/o John Swire & Sons, 8 Billiter Square, E.C.,

were balloted for and duly elected Fellows of the Society.

The following Candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended:—

Rev. Walter Briscombe, Wesleyan Minister, Hillam Royd, Abbey Park Road, Grimsby (proposed by R. Wilding);
Arthur Stanley Eddington, B.A., Trinity College, Cambridge (proposed by E. T. Whittaker); and
Dr. Edalgi Manekji Modi, F.C.S., F.Z.S., F.R.M.S., &c., Manufacturing and Consulting Chemist, Sleater Road, Bombay, India (proposed by J. D. Bharda).

Report of the Council to the Eighty-sixth Annual General Meeting of the Society.

The following table shows the progress and present state of the Society :—

	Compounders	Annual Subscribers	Total Fellows	Associates	Patron and Hon. Members	Grand Total
1904 December 31	262	382	644	49	3	696
Since elected	+ 3	+ 42	...	+ 3	...	...
Deceased	− 7	− 10	...	− 3	...	...
Resigned	...	− 14	...	...	...	...
Removals	+ 1	− 1	...	...	...	...
Expelled	...	− 1	...	...	...	...
1905 December 30	259	398	657	49	3	709

Major Hills' Account as Treasurer of the Royal

RECEIVED.

	£	s.	d.	£	s.	d.
Balances, 1904 December 31:—						
At Bankers', as per Pass-book	252	7	5			
In hand of Assistant Secretary on Account of Turnor and Horrox Fund	9	17	9			
				262	5	2
Dividends on £1,250 Metropolitan 3-per-cent. Stock	35	12	8			
Dividends on £932 19 0 Metropolitan 2½-per-cent. Stock	22	3	4			
Dividends on £3,400 East Indian Railway 3-per-cent. Debenture Stock	96	18	0			
Dividends on £3,200 London and North-Western Railway 3-per-cent. Debenture Stock	91	4	0			
Dividends on £4,000 Midland Railway 2½-per-cent. Debenture Stock	95	0	0			
Dividends on £500 Lancashire and Yorkshire Railway 3-per-cent. Consolidated Preference Stock	14	5	0			
Dividends on £1,860 Gas Light and Coke Co. 3-per-cent. Debenture Stock	53	0	2			
Dividends on £1,650 Commercial Gas Co. 3-per-cent. Debenture Stock	47	0	6			
Half-Year's Dividend on Investment of £1,600 of the McClean Bequest in £1,484 17*s.* 5*d.* Swansea Corporation 3½-per-cent. Stock ...	24	13	9			
				479	17	5
Received on account of Subscriptions:—						
Arrears	170	2	0			
Annual Contributions for 1905	577	10	0			
" " " 1906 in advance ...	8	8	0			
Admission Fees	98	14	0			
First Contributions	72	9	0			
				927	3	0
Composition Fees				99	15	0
Sales of Publications, &c.:—						
At Williams & Norgate's, 1904	33	18	6			
At Society's Rooms, 1905	52	14	6			
Sales of Photographs	32	9	0			
				119	2	0
Income Tax refunded by Commissioners of Inland Revenue				23	12	1
Bequest of the late Mr. Frank McClean				2,000	0	0
Loan from Bankers				400	0	0
Cheques Outstanding				16	19	6
				£4,328	14	2

Audited and found correct, 1906 Jan. 9:

WALTER W. BRYANT.
F. W. LEVANDER.
WM. SHACKLETON.

***Astronomical Society, from* 1905 *January* 1 *to December* 30.**

PAID.

	£	s.	d.	£	s.	d.
Assistant Secretary: Salary	250	0	0			
" " For editing Society's Publications	50	0	0			
Clerk's Salary	75	0	0			
				375	0	0
House Duty	2	12	6			
Fire Insurance	9	9	6			
				12	2	0
Printing *Memoirs*, vol. lv., &c. (Spottiswoode & Co.)	283	6	0			
" " vol. lvii. pts. 1, 2 " "	183	14	6			
Printing, plates, &c., *Monthly Notices* " "	597	19	3			
Printing, plates, &c., Appendix to *Monthly Notices* (Harrison & Sons)	5	11	0			
Printing, List of Fellows and Miscellaneous (Spottiswoode & Co.)	19	16	6			
Photo-plates for *Monthly Notices* (A. E. Dent & Co.)	19	13	7			
				1,110	0	10
Computation of Ephemerides in *Monthly Notices* ...				15	0	0
Turnor and Horrox Fund, purchase of books for Library	21	3	10			
Binding books in Library	32	9	6			
Cabinet for Card Catalogue in Library	5	10	0			
				59	3	4
Reproduction of Photographs, Hinton & Co. ...				34	2	8
Cataloguing astronomical literature for the International Catalogue of Scientific Literature ...				30	0	0
Expenses of Meetings	21	0	0			
Lantern Expenses	7	13	6			
Time Signal: Rental of Wire	5	0	0			
				33	13	6
Postage and Telegrams	94	8	7			
Carriage of Parcels, &c.	5	19	4			
Stationery (Spottiswoode & Co.)	5	17	0			
Sundry Stationery and Office Expenses	4	13	5			
				110	18	4
Repairs to Coelostat...				1	0	0
Decorations and Electric Light Installation, &c. (Geo. Trollope & Sons)	370	12	6			
Re-covering Seats in Meeting Room (Maple & Co.)	63	16	8			
Restoring Oil Paintings (F. Haines & Sons) ...	11	15	0			
				446	4	2
House Expenses: Allowance, and Sundry Expenses	62	1	2			
British Vacuum Cleaning Co. (cleaning books in Library)	13	4	0			
Coal and Gas	41	0	6			
Electric Light Expenses	14	0	6			
Sundry Fittings and Repairs	10	15	6			
Sundries	3	14	11			
				144	16	7
Jackson-Gwilt Gift to Mr. John Tebbutt				25	0	0
Purchase of £1,484 17*s.* 5*d.* Swansea Corporation 3½-per-cent. Stock (investment of part of the McClean Bequest)				1,600	0	0
Cheque Book and Deductions on Cheques... ...				0	10	8
Repayment to Assistant Secretary of amount due 1904 Dec. 31 on Petty Cash Account... ...				9	10	0
Interest on Loan from Bankers				0	19	9
Balances, 1905 December 30:—						
At Bankers', as per Pass-book	299	0	2			
Cheques not Credited till 1906	7	18	5			
In hand of Assistant Secretary on Account of Turnor and Horrox Fund...	4	13	11			
In hand of Assistant Secretary on Petty Cash Account	8	19	10			
				320	12	4
				£4,228	14	[illegible]

Report of the Auditors.

We have examined the Treasurer's accounts of receipts and expenditure for the year 1905, and have found and certified the same to be correct. The cash in hand on December 31, 1905, including the balance at the bankers', &c., amounted to £320 12*s.* 4*d.*

We regret to find that an overdraft of £400 at the bank has been found necessary; this, however, appears to be due to the expense of decorating the Society's premises and to a great increase in the bill for printing.

The funded property of the Society has been increased by the purchase of £1,484 17*s.* 5*d.* Swansea Corporation 3½-per-cent. Stock, being the investment of £1,600 of the McClean Bequest of £2,000.

The books, instruments, and other effects in the possession of the Society have been examined, and they appear to be in a satisfactory condition, with the exception of some of the instruments in the basement; in regard to which we strongly urge the desirability of taking steps to reduce their number by eliminating such instruments, or parts of instruments, as are no longer of any practical value or historical interest.

We have laid on the table a list of the names of those Fellows who are in arrear for sums due at the last Annual General Meeting of the Society, with the amount due against each Fellow's name.

(*Signed*) WALTER W. BRYANT.
F. W. LEVANDER.
WM. SHACKLETON.

Bequests to the General Funds of the Society.

The Carrington Bequest (1876).—A sum of £2,000 Consols. Sold in 1899 and the proceeds invested in the purchase of £1,881 14*s.* London and North-Western Railway 3-per-cent. Debenture Stock.

The McClean Bequest (1905).—A sum of £2,000. £1,600 of this sum invested in the purchase of £1,484 17*s.* 5*d.* Swansea Corporation 3½-per-cent. Stock.

Trust Funds.

The Turnor Fund: A sum of £464 18*s*. East Indian Railway 3-per-cent. Debenture Stock; the interest to be used in the purchase of books for the Library.

The Horrox Memorial Fund: A sum of £103 6*s*. East Indian Railway 3-per-cent. Debenture Stock; the interest to be used in the purchase of books for the Library.

The Lee and Janson Fund: A sum of £334 10*s*. 9*d*. East Indian Railway 3-per-cent. Debenture Stock; the interest to be given by the Council to the widow or orphan of any deceased Fellow of the Society who may stand in need of it.

The Hannah Jackson (née Gwilt) Fund: A sum of £309 18*s*. 6*d*. East Indian Railway 3-per-cent. Debenture Stock; the interest to be given in Medals or other awards, in accordance with the terms of the Trust.

Assets and Present Property of the Society, 1906 *January* 1.

	£	s.	d.	£	s.	d.
Balances, 1905 December 31:—						
At Bankers', as per Pass-book	299	0	2			
Cheques not credited till 1906	7	18	5			
In hand of Assistant Secretary:—						
Turnor and Horrox Fund	4	13	11			
Petty Cash Account	8	19	10			
	320	12	4			
Less cheques outstanding	16	19	6			
				303	12	10
Due on account of Subscriptions:—						
1 Contribution of 5 years' standing	10	10	0			
6 Contributions of 4 "	50	8	0			
13 " 3 "	81	18	0			
27 " 2 "	113	8	0			
57 " 1 year's standing	119	14	0			
	375	18	0			
Less paid in advance	8	8	0			
				367	10	0
				671	2	10
Less loan from Bankers				400	0	0
				271	2	10
Due for Photographs sold				0	4	0
Due from Messrs. Williams & Norgate for sales of Publications, 1905				11	16	0

£3,400 East Indian Railway 3-per-cent. Debenture Stock, including the Turnor Fund, the Horrox Memorial Fund, the Lee and Janson Fund, and the Hannah Jackson (*née* Gwilt) Fund.

£3,200 London and North-Western Railway 3-per-cent. Debenture Stock (including the Carrington Bequest).

£4,000 Midland Railway 2½-per-cent. Debenture Stock.

£500 Lancashire and Yorkshire Railway 3-per-cent. Consolidated Preference Stock.

£1,860 Gas Light and Coke Co. 3-per-cent. Debenture Stock.

£1,650 Commercial Gas Company 3-per-cent. Debenture Stock.

1,250 Metropolitan 3-per-cent. Stock.

£932 19*s*. 0*d*. Metropolitan 2½-per-cent. Stock.

£1,484 17*s*. 5*d*. Swansea Corporation 3½-per-cent Stock (being £1,600 of the McClean Bequest of £2,000).

Astronomical and other Manuscripts, Books, Prints, and Instruments.

Furniture, &c.

Stock of Publications of the Society.

One Gold Medal.

Celestial Photographs.

The following is a list of reproductions of Celestial Photographs published by the Royal Astronomical Society for sale to the Fellows :—

R.A.S. Ref. No.	Subject.	Photographed by
1	Total Solar Eclipse, 1889 January 1	W. H. Pickering
2	Total Solar Eclipse, 1893 April 16	J. M. Schaeberle
3	Total Solar Eclipse, 1886 August 29	A. Schuster
4	Nebulæ in the *Pleiades*	Isaac Roberts
5	Nebula M 74 *Piscium* (N.G.C. 628)	Isaac Roberts
6	Great Nebula in *Orion*	Isaac Roberts
7	Milky Way near M 11	E. E. Barnard
8	Milky Way near Cluster in *Perseus*	E. E. Barnard
9	Comet *c* 1893 IV. (Brooks), 1893 October 21	E. E. Barnard
10	Comet *a* 1892 I. (Swift), 1892 April 7	E. E. Barnard
11	Nebula about η *Argûs*	David Gill
12	Portion of Moon (Hyginus-Albategnius)	Loewy and Puiseux
13	Comet *c* 1893 IV. (Brooks), 1893 October 22	E. E. Barnard
14	Comet *c* 1893 IV. (Brooks), 1893 October 20	E. E. Barnard
15	Comet *c* 1893 IV. (Brooks), 1893 November 10	E. E. Barnard

R.A.S. Ref. No.	Subject.	Photographed by
16	Comet *a* 1892 I. (Swift), 1892 April 26	E. E. Barnard
17	Comet *f* 1892 III. (Holmes), 1892 November 10	E. E. Barnard
18	Comet *a* 1892 I. (Swift), 1892 April 18	E. E. Barnard
19	Portion of Moon (Alps, Apennines; &c.)	Loewy and Puiseux
20	Nebula in *Andromeda*	Isaac Roberts
21	*Jupiter*, 1892 September 26	Lick Observatory
22	Cluster M 13 *Herculis* (N.G.C. 6205)	W. E. Wilson
23	Total Solar Eclipse, 1893 April 16 (5 sec.)	J. Kearney
24	Total Solar Eclipse, 1893 April 16 (20 sec.)	J. Kearney
25	The Moon (Age 7^d 3^h)	Lick Observatory
26	The Moon (Age 12^d $6\frac{1}{2}^h$)	Lick Observatory
27	The Moon (Age 16^d 18^h)	Lick Observatory
28	The Moon (Age 23^d 8^h)	Lick Observatory
29	The Sun, 1892 February 13	Roy. Obs., Greenwich
30	The Sun, 1892 July 8	Roy. Obs., Greenwich
31	Portion of Moon (Region of Maginus)	Loewy and Puiseux
32	The Moon (Age 14^d 1^h)	Lick Observatory
33	Portion of Moon (Ptolemæus, &c.)	Lick Observatory
34	Portion of Moon (Mare Serenitatis)	Lick Observatory
35	Portion of Moon (Clavius, Licetus, &c.)	Lick Observatory
36	Portion of Moon (Regiomontanus, &c.)	Lick Observatory
37	Portion of Moon (Tycho, Thebit, &c.)	Lick Observatory
38	Portion of Moon (Theophilus, &c.)	Lick Observatory
39	Total Solar Eclipse, 1896 August 9 (3 sec.)	S. Kostinsky
40	Total Solar Eclipse, 1896 August 9 (26 sec.)	A. Hansky
41	Cluster M 56 *Lyræ* (N.G.C. 6779)	
42	Nebulæ M 81, 82 *Ursæ Majoris* (N.G.C. 3031, 3034)	
43	Cluster M 56 *Lyræ* (enlarged) (N.G.C. 6779)	
44	Solar Corona, 1871 December 12, Baikul	H. Davis
45	Solar Corona, 1875 April 6, Siam	Lockyer and Schuster
46	Solar Corona, 1878 July 29, Wyoming	W. Harkness
47	Solar Corona, 1882 May 17, Egypt	Abney and Schuster
48	Solar Corona, 1883 May 6, Caroline Island	Lawrance and Woods
49	Solar Corona, 1885 September 9, Wellington, N.Z.	Radford
50	Solar Corona, 1886 August 29, Grenada, W.I.	A. Schuster
51	Solar Corona, 1887 August 19, Japan	M. Sugiyama
52	Solar Corona, 1889 January 1, California	W. H. Pickering
53	Solar Corona, 1889 December 22, Cayenne	J. M. Schaeberle
54	Solar Corona, 1893 April 16, Fundium	J. Kearney

R.A.S. Ref. No.	Subject.	Photographed by
55	Solar Corona, 1893 April 16, Brazil	A. Taylor
56	Great Nebula in *Orion*	W. E. Wilson
57	Dumb-bell Nebula, *Vulpecula* (N.G.C. 6853)	W. E. Wilson
58	Spiral Nebula, *Canes Venatici* (N.G.C. 5194)	W. E. Wilson
59	Ditto (enlarged) (N.G.C. 5194)	W. E. Wilson
60	Annular Nebula, *Lyra* (N.G.C. 6720)	W. E. Wilson
61	Meteor Trail and Comet Brooks, 1893 November 13	E. E. Barnard
62	Total Solar Eclipse, 1898 January 22 (5 sec.)	W. H. M. Christie
63	Total Solar Eclipse, 1898 January 22 (20 sec.)	W. H. M. Christie
64	Solar Corona, 1896 August 9, Novaya Zemlya	G. Baden-Powell
65	Solar Corona, 1898 January 22, Pulgaon, India	E. H. Hills
66	Nebula in *Andromeda*	Roy. Obs., Greenwich
67	Spectrum of Sun's limb, 1898 January 22	E. H. Hills
68	Annular Nebula, *Lyra* (N.G.C. 6720)	Lick Observatory
69	Dumb-bell Nebula, *Vulpecula* (N.G.C. 6853)	Lick Observatory
70	Spiral Nebula, *Canes Venatici* (N.G.C. 5194–5)	Lick Observatory
71	Spiral Nebula, *Ursa Major* (N.G.C. 5457)	Lick Observatory
72	Trifid Nebula, *Sagittarius* (N.G.C. 6514)	Lick Observatory
73	Great Nebula in *Orion*	Lick Observatory
74	Cluster M 13 *Herculis* (N.G.C. 6205)	Lick Observatory
75	Solar Surface with Faculæ	G. E. Hale
76	Faculæ and Prominences	G. E. Hale
77	Total Solar Eclipse, 1898 Jan. 22 (¾ sec.)	W. H. M. Christie
78	Nebula H V. 14 *Cygni* (N.G.C. 6992)	W. E. Wilson
79	Portion of Moon (Theophilus, &c.)	Yerkes Observatory
80	Total Solar Eclipse, 1900 May 28 (30 sec.)	E. E. Barnard
81	Comet 1901 I., 1901 May 4	Roy. Obs., Cape of G. H.
82	Comet 1901 I., 1901 May 6	Roy. Obs., Cape of G. H.
83	Comet 1901 I., 1901 May 9	Perth Obs., W. Australia
84	Solar Surface with Faculæ	H. Deslandres
85	Solar Prominences	H. Deslandres
86	Nebula about Nova *Persei*, 1901 September 20	G. W. Ritchey
87	Nebula about Nova *Persei*, 1901 November 13	G. W. Ritchey
88	Total Solar Eclipse, 1901 May 18 (10 sec.)	F. W. Dyson
89	Total Solar Eclipse, 1901 May 18 (40 sec.)	F. W. Dyson
90	Comet *b* 1902 III. (Perrine), 1902 Sept. 29	Roy. Obs., Greenwich
91	Portion of Moon (Mare Serenitatis, &c.)	Yerkes Observatory
92	Portion of Moon (Rough Crater Region, Mare Nubium)	Yerkes Observatory

R.A.S. Ref. No.	Subject.	Photographed by
93	Portion of Moon (Tycho, Theophilus, &c.)	Yerkes Observatory
94	Portion of Moon (Bullialdus to Copernicus)	Yerkes Observatory
95	Portion of Moon (Copernicus)	Yerkes Observatory
96	Great Nebula in *Orion*	Yerkes Observatory
97	Great Nebula in *Orion* (Central portion)	Yerkes Observatory
98	Nebula in *Andromeda*	Yerkes Observatory
99	Nebula in *Cygnus* (N.G.C. 6960)	Yerkes Observatory
100	Nebula in *Cygnus* (N.G.C. 6992)	Yerkes Observatory
101	Cluster M 13 *Herculis* (N.G.C. 6205)	Yerkes Observatory
102	Cluster M 15 *Pegasi* (N.G.C. 7078)	Yerkes Observatory
103	Solar Surface with Faculæ	Yerkes Observatory
104	The Moon, 1900 April 5	P. Puiseux
105	The Moon, 1902 November 13	P. Puiseux
106	The Moon, 1903 February 6	P. Puiseux
107	The Moon, 1903 September 12	P. Puiseux
108	Nebulosity about 15 *Monocerotis*	E. E. Barnard
109	Milky Way about β *Cygni*	E. E. Barnard
110	Nebulosity near α *Cygni*	E. E. Barnard
111	Milky Way near χ *Cygni*	E. E. Barnard
112	Star cloud in *Sagittarius*	E. E. Barnard
113	Milky Way in *Cepheus*	E E. Barnard
114	Milky Way about M 8	E. E. Barnard
115	Milky Way about θ *Ophiuchi*	E. E. Barnard
116	Milky Way near N.G.C. 6475	E. E. Barnard
117	Great Nebula near ρ *Ophiuchi*	E. E. Barnard
118	Milky Way about 58 *Ophiuchi*	E. E. Barnard
119	Milky Way near *Omega* nebula	E. E. Barnard
120	Star cloud in *Sagittarius*	E. E. Barnard
121	Nebula about ν *Scorpii*	E. E. Barnard
122	Sun, 1905 January 30	Roy. Obs., Greenwich
123	Sun-spot, 1905 January 30	Roy. Obs., Greenwich
124	Sun, 1905 January 31	Roy. Obs., Greenwich
125	Sun-spot, 1905 January 31	Roy. Obs., Greenwich
126	Sun, 1905 February 2	Roy. Obs., Greenwich
127	Sun-spot, 1905 February 2	Roy. Obs., Greenwich
128	Sun, 1905 February 3	Roy. Obs., Greenwich
129	Sun-spot, 1905 February 3	Roy. Obs., Greenwich
130	Sun, 1905 February 5	Roy. Obs., Greenwich
131	Sun-spot, 1905 February 5	Roy. Obs., Greenwich

R.A.S. Ref. No.	Subject.	Photographed by
132	Sun, 1905 February 8	Roy. Obs., Greenwich
133	Sun-spot, 1905 February 8	Roy. Obs., Greenwich
134	Nebula near ψ *Eridani*, 1905 January 8	Max Wolf
135	Nebula M 33 *Trianguli*	Isaac Roberts
136	Nebula in *Perseus* (N.G.C. 1499)	Isaac Roberts
137	Nebula in *Monoceros* (N.G.C. 2237–9)	Isaac Roberts
138	Nebula ♅ V. 24 *Comæ*	Isaac Roberts
139	Nebulæ ♅ V. 42, &c., *Comæ*	Isaac Roberts
140	Nebulæ ♅ V. 37 *Cygni*	Isaac Roberts
141	Nebula Index Cat. 405 *Persei*	Isaac Roberts
142	Cluster ♅ VI. 33–4 *Persei*	Isaac Roberts
143	Cluster ♅ VI. 30 *Cassiopeiæ*	Isaac Roberts
144	Eclipse, 1905 August 30 (5 sec.)	W. H. M. Christie
145	Eclipse, 1905 August 30 (20 sec.)	W. H. M. Christie
146	Eclipse, 1905 August 30 (7 sec.)	W. H. M. Christie
147	Eclipse, 1905 August 30 (20 sec.)	W. H. M. Christie
148	Eclipse, 1905 (Portion) August 30	W. H. M. Christie

Nos. 44–55 and Nos. 64, 65 and 147 form a series of corona photographs, oriented and reduced to the same scale.

The above photographs are now on sale to Fellows as prints, either platinotype or aristotype, mounted on sunk cut-out mounts, measuring 12 inches by 10 inches; also unmounted, and as lantern slides. Nos. 44–55 and Nos. 64 and 65 are also supplied as transparencies, $6\frac{1}{4}$ inches square.

Price of prints, mounted, 1*s.* 6*d.* each, unmounted, 1*s.* each; lantern slides, 1*s.* each; packing and postage extra.

Transparencies, $6\frac{1}{4}$ inches square (Nos. 44–55 and Nos. 64 and 65), 3*s.* 6*d.* each.

Orders to be addressed to W. H. Wesley, Burlington House, London, W. In ordering prints or slides the R.A.S. Reference No. only need be quoted, but in the case of prints it should be stated whether platinotypes or aristotypes are required, and whether mounted or unmounted.

The Gold Medal.

The Council have awarded the Society's Gold Medal to Professor W. W. Campbell for his spectroscopic researches, which have greatly increased our knowledge of Stellar motions. The President will lay before the Society the grounds upon which the award has been founded.

Publications of the Society.

During the past year vol. lv. of the *Monthly Notices*, with two Appendices reprinted from the *Proceedings of the Royal Society*, has been published.

In consequence of the increase in the size of the page of the *Proceedings* the reprinting of these Appendices is now discontinued. The Reports of the Joint Eclipse Meeting of the Royal and Royal Astronomical Societies on 1905 October 19 will, however, be issued to the Fellows as a separate publication.

The Council have decided that each paper in the *Memoirs* shall be printed and circulated separately, and the following have been issued during the past year :—

Vol. lvii. pt. 1. S. A. Saunder, The Determination of Selenographic Positions and the Measurement of Lunar Photographs. Third paper : Results of the Measurement of Four Paris Negatives.

Vol. lvii. pt. 2. E. W. Brown, Theory of the Motion of the Moon, containing a New Calculation of the Expressions for the Co-ordinates of the Moon in the Terms of the Time. Part IV., Chapters VII.–IX.

Vol. lvi. of the *Memoirs*, containing Mr. Lewis's Memoir on the measures of the double-stars in Struve's *Mensuræ Micrometricæ*, is in the press, and will be published in the course of the present year.

Obituary.

The Council regret that they have to record the loss by death of the following Fellows and Associates during the past year :—

Fellows :—Thomas Michael Almond.
Walter Ernest Besley.
George Cox Bompas.
Ralph Copeland.
Edward Crofton.†
Edward Crossley.*
John Dansken.
Rev. Adam Storey Farrar.
Lord Grimthorpe.
Rev. Timothy Harley.†
Charles Horsley.*
Rev. Samuel J. Johnson.
Lieut.-Col. Henry S. G. S. Knight.†
Thomas Edward Knightley.
George Richard Stevens.
Rev. William R. M. Waugh.
Sir W. J. Lloyd Wharton.

Associates :—Paul Henry.*
Otto Struve.
Pietro Tacchini.

Obituary notices are also given of E. H. R. Coleman and Charles Jasper Joly, who died in January 1906.

Walter Ernest Besley was born at Tiverton, North Devon, in 1877, the elder son of Walter Besley. He was educated on the classical side at Heavitree College, near Exeter, and, for one year, in London. In 1896 he obtained by examination a Second Division Civil Service clerkship, and was appointed to the office of the Local Government Board in Whitehall, where, until his death, his work lay, under its former and present Superintendents, the late Sir R. Thorne and Mr. W. H. Power, in the Public Health Department.

In 1895, when as yet only 17 years of age, he commenced to observe meteors and the brighter variable stars, communicating

* Obituary in *Annual Report*, 1905.
† Death not reported till 1905.

his results to the *English Mechanic*. In 1898, on the death of his father, Mrs. Besley came to live with her sons in London, and a house was taken adjoining the north side of Clapham Common; here the greater part of his astronomical work was accomplished. In 1900 he was appointed Director of the Meteor Section of the British Astronomical Association, having joined the Association in 1896, and having then applied himself with good effect to variable star and meteor observations; and he held this office until in April 1905 he was compelled by increasing ill-health to resign it.

Mr. Besley was elected a Fellow of the Royal Astronomical Society in January 1902, and was at first an occasional attendant at its meetings, but in the last two years, chiefly on account of illness, he was unable to be present. In spite of attempts to recruit his health by visits to his native Devonshire—where his time was chiefly taken up in editing meteoric observations—his condition gradually became more serious, and on the 29th of June 1905, at the early age of 27 years, this devoted and able observer passed away.

[The Council are indebted to Professor A. S. Herschel for the above particulars.]

George Cox Bompas was born on the 18th of April 1827, being the second son of the late Serjeant Bompas. He was educated privately, and was admitted as a solicitor in 1850, continuing to practise till 1903. He married in 1860 Mary Anne Scott Buckland, daughter of the Rev. Wm. Buckland, Dean of Westminster. From an early period Mr. Bompas took an interest in astronomy; his special studies were on periodic meteor showers, and he latterly devoted his attention to the Zodiacal Light and the solar motion in space. He was elected a Fellow of the Society on the 14th of December 1894; he was also a Fellow of the Royal Geographical Society, the Geological Society, the Palæontological Society, and other institutions. He died on the 23rd of May 1905, after a long illness, leaving a widow and four children.

Everard Home Roberts Coleman was born in London in January 1818. Like his father before him, he was educated at Christ's Hospital. He was one of the forty boys in the Mathematical School, a branch of the Hospital founded by Charles II. with the view of training lads for the Navy. An interesting occurrence of his school days was a visit of the King (William IV.), the Queen, and Princess Victoria, when his Majesty's attention was attracted by a drawing by young Coleman of the island of St. Helena. The King took it from the boy's hands, and, after explaining it to the royal party, asked to be allowed to keep it. Soon afterwards Coleman received from the King an appointment in the Admiralty, and five years later was transferred to the Record and Registry Office for Shipping and Seamen, where he became

Assistant Registrar, an office which he held till his retirement seventeen years ago. He was well known as an archæologist and antiquarian, was the oldest living member of the London and Middlesex Archæological Society, and one of the original contributors to *Notes and Queries*; he was also a Fellow of the Royal Geographical and Historical Societies. Though of a retiring disposition, he took an interest in public affairs in connection with the district of St. Pancras, in which he lived, and in local charitable institutions.

He died on the 28th of January 1906, at the age of 88, and leaves a widow, a daughter, and seven sons. With one exception Mr. Coleman was the oldest Fellow of the Royal Astronomical Society, having been elected in June 1853.

Ralph Copeland was born on the 3rd of September 1837, at Moorside Farm, near Woodplumpton, in Lancashire, and while still a child lost his father. He received his first instruction from a handloom weaver, who taught his pupils while working at his loom, until he at the age of about eight years proceeded to the grammar school of Kirkham. In 1853 he went to Australia and spent five years in the colony of Victoria, most of the time on a sheep run at the foot of the Australian Alps, though he was also for some time infected by the then raging mania for gold digging and made his way to the wild Omeo district. In after years Copeland was always fond of recalling incidents from this stirring period of his life, and it is much to be regretted that he could never be persuaded to write down his reminiscences, as they would have formed most entertaining reading.

Rough as the life was which he led during these five years, Copeland did not neglect to cultivate his mind, and it was during that time that he became deeply interested in astronomy. At his request his mother sent him a small telescope, and by means of this and a few popular books he made his first acquaintance with the heavens. Finally his thirst for knowledge decided him to leave Australia, and he started for home in the summer of 1858 in a clipper *viâ* Cape Horn. On the voyage he made experiments as to the visibility of stars in daylight in the tropics, and succeeded in keeping *Jupiter*, and even *Sirius*, in sight until the Sun showed above the horizon; but after glancing at the Sun he was unable to find *Sirius* again, though he succeeded in picking up *Jupiter* for a short time.* He also followed with close attention the appearance and rapid development of Donati's Comet. He had wished to enter Cambridge University, but had to give up this plan and eventually entered the works of Beyer, Peacock & Co., locomotive engineers, of Manchester, as a volunteer-apprentice. Here he carried on the study of the stars commenced in Australia, and was fortunate enough to find

* See *Copernicus*, vol. iii. p. 204.

among his fellow-apprentices several who shared his tastes and joined him in fitting up a small observatory for a 5-inch refractor by Cooke, at West Gorton, near Manchester. Copeland's first recorded observation was of the occultation of κ *Cancri* on the 26th of April 1863, which Mr. Dawes communicated to the *Monthly Notices* (vol. xxiii. p. 221), and which attracted some attention at the time, as the disappearance of the star at the dark limb did not appear to be instantaneous, a fact which was denied by some observers but confirmed by others.

In the end Copeland resolved to desert mechanical engineering and to devote his life to astronomy, being also influenced by the bad prospects of trade in Lancashire due to the cotton famine during the American Civil War. Although he had been a married man for about five years (he had married a first cousin, Susannah Milner, in 1859) and was the father of a little girl, he made up his mind to study at a German University. In the spring of 1865 he matriculated in the University of Göttingen and commenced the study of astronomy, physics, and mathematics. Among his fellow-students were Behrmann, Börgen, and Schur, with whom he not only attended the lectures of Klinkerfues, Weber, Stern, and other professors, but also had the opportunity of becoming familiar with the use of astronomical instruments. The observatory was in charge of Klinkerfues, whose excellence as a teacher and charm of manner greatly endeared him to his pupils. In July 1866 Copeland had the misfortune to lose his wife, who died leaving him an infant son. In the summer of 1867 Börgen and he decided to carry out a considerable piece of work with one of the meridian instruments in the observatory, and as the Astronomische Gesellschaft was about to organise zone observations of all stars down to the ninth magnitude north of $-2°$ declination, they chose the zones $-1°$ and $-0°$ and commenced observing them with the Reichenbach transit circle on the 2nd of June 1867. Early in the following year Copeland took up his residence at the observatory, where his fellow-observer had also rooms, and in January 1869 the last zone was observed, while the reductions were so far advanced that the resulting catalogue of star-places could be published in the following summer. The work had been commenced before the programme of the zone work of the Gesellschaft had been settled, and it turned out that the plan adopted by the two Göttingen observers differed from that of the international undertaking, as the places of standard stars had been taken from the *Nautical Almanac*, while the stars below the ninth magnitude observed by Lalande and Bessel had not been re-observed. The catalogue was therefore not accepted by the Council of the Gesellschaft as a part of their undertaking, and the zone $-2°$ to $0°$ was some years later assigned to the Nicolajew Observatory; but as the Nicolajew Catalogue ($-2°$ to $+1°$) did not appear till the year 1900, the Göttingen Catalogue was for thirty years the chief modern authority for the

zone in question, while its earlier epoch and its accuracy make it permanently valuable in cases of proper motion.

Before the actual publication of the star catalogue Copeland had already entered on a different line of scientific work. Early in 1869 it was decided to send out a German Arctic expedition under Captain Koldewey, the aim of which should be to explore the east coast of Greenland as far north as possible. It occurred to Koldewey that it would be of great interest to measure an arc of meridian so near the Pole. Börgen, whom he consulted as to the feasibility of the idea, pointed out that it would be impossible to attempt to reach results of permanent value, since the expedition could not be devoted to this work alone, but that it would be most useful to make a detailed geodetic reconnaissance, on which at some future time a regular measurement of an arc could be based. Should this be made part of the work of the expedition he would be disposed to join it, but in that case Copeland ought also to join, since one astronomer could not possibly carry out the work alone. On hearing this the same evening, Copeland at once was fired with enthusiasm at the prospect of taking part in a scientific investigation of a novel kind, and spent half the night talking about the methods to be followed and the instruments to be used.* The preparations for the expedition were rapidly pushed on, while the two friends at the same time put the finishing touch to their studies by taking out the degree of Doctor of Philosophy, Copeland's dissertation being on the orbital motion of *α Centauri* (*Über die Bahnbewegung von α Centauri*, Göttingen, 1869, 24 pp. 8°).

The expedition started from Bremerhafen on the 15th of June 1869. It consisted of the *Germania* (on board which Copeland was) and a small sailing vessel, the *Hansa*. The latter was to have returned the same autumn after unloading stores, but it became unfortunately separated from its companion off the east coast of Greenland and was crushed in the ice, though the crew, after drifting on an ice floe for seven months, succeeded in reaching one of the Danish settlements on the west coast. The *Germania* safely reached the east coast, and wintered in latitude 74° 32′. Copeland showed himself as a most useful member of the expedition owing to his training as a mechanical engineer, as well as by his skill in the use of the rifle, whereby he contributed greatly to keeping the larder supplied with fresh meat. During the winter he and Dr. Börgen made regular meteorological and magnetic observations, and in February 1870 the work was commenced of selecting the nearest stations and erecting cairns on them for the geodetic work. In the course of the next two months stations slightly more distant were visited by Copeland without the help of his friend, who had been badly wounded by a bear in the beginning of March, whereby much precious time

* The writer is indebted to Professor Börgen for these particulars, which he wishes to be put on record here, as it was stated in an obituary notice after Copeland's death that he joined the expedition from love of adventure.

was lost. It was, therefore, not till the beginning of May that a base, 709 metres in length, was measured close to the ship, after which the two observers started northward in a sledge. But the season was by that time too far advanced, the snow was too soft, and a rapid thaw set in early in June, rendering sledge travelling impossible. Instead of continuing operations as far as 75° 45′, as intended, it became necessary to stop at 75° 11′·5. The observations were made with an altazimuth with 5-inch circles, the latitude of the two end stations being determined by altitudes of the Sun. A good deal of valuable experience had been gained as to the best hours for taking observations and the most suitable localities for stations, which ought to be of great use for future geodetic observers in high latitudes. The results were published in the second volume of the work *Die Zweite Deutsche Nordpolarfahrt* (Leipzig, 1874).*

Soon after his return from Greenland Copeland was appointed Assistant Astronomer at Lord Rosse's Observatory at Birr Castle, and entered on his duties there in January 1871. In the following December he married Theodora, daughter of the distinguished orientalist Professor Benfey, of Göttingen. This marriage brought him three daughters and a son. At Birr Castle Copeland was for the first two years chiefly occupied with the observations on the Moon's radiant heat embodied in Lord Rosse's paper on this subject in the *Philosophical Transactions*, 1873. In 1874 he was appointed Assistant in the Dublin University Observatory at Dunsink, but was granted leave of absence to accompany Lord Lindsay to Mauritius to observe the transit of *Venus*. On the outward voyage, in the yacht *Venus*, a call was made at the small uninhabited island of Trinidad, in the South Atlantic, where Copeland was fortunate enough to discover a great tree-fern (*Cyathea Copelandi*), groves of which are found only in the loftier and nearly inaccessible parts of the island. The observations of the transit were only partly successful, owing to cloudy weather. On the eventful day Copeland observed with a 6-inch equatorial and double-image micrometer.

This expedition was the beginning of his connection with the observatory of Lord Lindsay (now Lord Crawford) which lasted for the remainder of his life. He stayed only a little over a year at Dunsink (where he observed red stars with the transit circle), and took charge of the Dun Echt observatory in the summer of 1876 in succession to Mr. Gill. He was singularly well suited to the post, as his great mechanical skill was particularly useful in an observatory where an unusually great number of astronomical and physical instruments had been collected, while his thorough knowledge of scientific literature and fondness of rare books made him a valuable help to Lord Crawford in forming a great astronomical library. The Mauritius expedition had left a troublesome legacy in the shape of an immense amount of

* A short account of the geodetic work (with a map) is given by Dr. Börgen in the *Vierteljahrsschrift d. a. G.*, vol. vi. p. 280.

unreduced observations connected with the latitude and longitude work, which gave Copeland a great deal to do during the first five or six years at Dun Echt. The results were brought out in 1885 in a quarto volume of more than 500 pages, the third volume of the *Dun Echt Observatory Publications*. An interesting result of this work was the discovery of a considerable deflection of the plumb line in the island of Mauritius, the sum of the observed deviations at the Government Observatory and the German station being no less than 56″·6, a natural consequence of the island being but the exposed summit of a mountain some 15,000 feet high, standing on the floor of the ocean, while the observations were made some 3,000 feet below the highest points.

Among the instruments at Dun Echt Copeland specially devoted himself to the 15-inch refractor, with which he regularly observed every comet which became visible, while he for some years also computed elements and ephemerides of them. Most of these computations were published in the *Dun Echt Circulars*, by means of which Lord Crawford for ten years distributed news of discoveries of comets, &c. In January 1881 Copeland became joint editor of "*Copernicus*, an international Journal of Astronomy" (3 vols. 1881–84), which, though printed in Dublin, was the organ of the Dun Echt Observatory. As Copeland was always somewhat inclined to postpone the final completion and publication of his scientific work, it was fortunate that this journal for some years supplied a much-needed stimulus, and some of his best work is accordingly to be found in *Copernicus*. The end of the year in which he settled at Dun Echt witnessed the outburst of Schmidt's Nova *Cygni*, the remarkable spectrum of which was regularly observed by Copeland in January and February 1877, and on the 2nd of September he made the then totally unexpected discovery that the spectrum had become reduced to a single bright line—a discovery which forms an epoch in the history of our knowledge of temporary stars. The spectroscope was also turned on every comet visible at Dun Echt, and a specially rich harvest of results was furnished by the two great comets of 1881, Wells' Comet 1882 I, and the Great Comet of 1882. In the spectrum of Wells' comet Copeland and his assistant, Mr. Lohse, noticed on the 27th of May the presence of the yellow sodium line, both components of which were beautifully seen some days later, while the widely opened slit allowed the image of the comet to be clearly seen in the light of the D lines. Even these interesting observations were surpassed by those made on the 18th of September 1882, in full daylight, of the great comet close to the Sun. Not only were the bright D lines seen again, but also a whole row of bright lines, the best defined of which were afterwards identified with prominent iron lines, while the numerous dark Fraunhofer lines of the daylight spectrum supplied a background which showed that the comet lines were displaced towards the red end of the

spectrum, indicating that the comet was receding from the earth. All these important observations are published in vol. ii. of *Copernicus*.

In October 1882 Copeland started for Jamaica, where he successfully observed the transit of *Venus*. During his stay in the island it occurred to him that it would be of interest to test the suitability of the slopes of the Andes for astronomical observation, and, as Lord Crawford liberally met the necessary outlay for this digression, Copeland made his way across the Isthmus of Panama towards the end of December. As the expedition had not been thought of before leaving home, his outfit was rather scanty, consisting of some meteorological instruments, a small Vogel spectroscope, and a six-inch refractor by Simms, the fine equatoreal mounting of which had to be left behind as far too heavy for mule transport. In its place a light mounting was despatched from Dun Echt, together with a Browning automatic spectroscope, but they were delayed on the way, owing to the war between Chile and Peru, and did not reach him till the 2nd of June 1883, and then only in a damaged condition. He had first intended to go to Quito, but on reaching Gauyaquil this was found to be impossible, owing to revolution, so he had to go on to Peru. Landing at Mollendo on the 2nd of February, he proceeded to Arequipa by the interesting railway and utilised an enforced delay of a week in that town to get a 6-inch lathe transformed into a very fair equatorial mounting. The rainy season was now in full swing, and when he reached Vincocaya (14,360 feet above the sea) nothing could be done there, for which reason he went on to La Paz, in Bolivia, across the Lake of Titicaca, to gain experience of the means of transport and the state of the sky in that country. He established himself at Puno, on Lake Titicaca (12,500 feet), from the 17th of March to the 2nd of June, after which he again observed at Vincocaya till the 27th of June before embarking for Panama. With the Vogel spectroscope he found a number of stars with bright line spectra and several star-like planetary nebulæ, and would doubtless have accomplished much more in this direction if his instrumental equipment had been better. Though the direct results of his observations were not numerous the expedition had shown the great possibilities of a thoroughly equipped astronomical expedition or a permanent observatory in the regions visited by him; and in after years, when Harvard College Observatory had established a branch at Arequipa, it was a great satisfaction to Copeland to feel that he had been the pioneer of Peruvian astronomy, although he had rather advocated the choice of some place between La Paz and Lake Titicaca. His "Account of some Recent Astronomical Experiments at High Elevations in the Andes" appeared in vol. iii. of *Copernicus*, which volume also contains a short account of his visit to various American observatories in August 1883 on his way home.*

* Two lengthy "Reisebriefe aus Südamerika," dated February 1883, are

After his return home in September 1883 Copeland found enough to do in preparing his results for publication and seeing the Mauritius volume through the press. He next resumed his spectroscopic work whenever a special opportunity offered itself, as on the appearance of the new star in the nebula of *Andromeda* and on the discovery of Mr. Gore's variable star in *Orion* (*Monthly Notices*, vols. xlvi. and xlvii.). In 1886 the observatory was enriched by a magnificent star-spectroscope made by Messrs. Cooke & Sons. Almost the first time this instrument was directed to the nebula in *Orion* it revealed the presence of the D_3 line in its spectrum, and soon afterwards of a very faint line at W. L. 447·6 (*Monthly Notices*, vol. xlviii. p. 360). Encouraged by this unexpected discovery Copeland commenced a regular spectroscopic survey of the brighter nebulæ, and (judging from private letters written at that time) these observations made with a very powerful instrument would, if persevered in, have produced very valuable results, but his removal from Dun Echt unfortunately caused them to be interrupted, and they were never resumed. In 1887 an observing station was established on the top of the Barmekin Hill, close to Dun Echt, for the purpose of studying the low Sun spectrum by the aid of a Rowland grating and an ingenious and rapid recording apparatus; but his journey to Russia in the summer of that year to observe the total eclipse of the Sun (of which he saw nothing, owing to clouds) prevented Copeland from sharing in this interesting work, which Dr. Becker carried out most successfully. During that year and the following one every spare moment was devoted to the revision and passing through the press of the *Catalogue of the Crawford Library*. It had always given Copeland great pleasure to acquire rare and valuable books and memoirs for this great collection, particularly in the department of comets, and almost to the last year of his life he lost no reasonable opportunity of adding to it. The catalogue, which was published in 1890, is one of the most valuable guides to astronomical literature (particularly previous to 1700) and is simply indispensable to the collector.

The years which Copeland was destined to spend at Dun Echt had now come to an end. They were undoubtedly the happiest years of his life. Surrounded by his family and free from all distraction by extraneous duties or routine work, he was able to make full use of the splendid opportunities for original work afforded by the instruments and library under his charge. No wonder that he was very attached to the place and was glad to return to it several times to spend his summer holidays in his old house and to meet again many friends he had made in the neighbourhood.

In August 1888 Professor Piazzi Smyth resigned the offices of Astronomer Royal for Scotland and Professor of Astronomy in

published in the *Deutsche Geographische Blätter* (vol. vi. Bremen, 1883); they give a most vivid description of his journey from Mollendo to La Paz and of a trip to the Island of Coati in Lake Titicaca.

the University of Edinburgh. For some years previously the question of reorganising the Edinburgh Observatory had been under consideration, and it had even been proposed to hand it over to the University. But this was prevented by the noble liberality of Lord Crawford, who offered the Government to present the whole of the instrumental equipment of his own observatory, together with his astronomical library, to the nation, on the sole condition that the thus enriched Edinburgh Observatory should be maintained as a Royal Observatory. The offer was accepted and Copeland was appointed to the vacant offices on the 29th of January 1889, and removed to Edinburgh in the following April. The first subject to engage his attention was naturally the selection of a site for the new observatory, and after a careful examination of the neighbourhood of Edinburgh he finally chose Blackford Hill, as being south of and quite clear of the smoke of the city, and yet not at too great a distance from the University where he had to lecture. From the beginning he was deeply interested in his professorial duties, and though it was at first uphill work to attract students to the astronomical lectures (which his predecessor had managed to evade for many years) he gradually succeeded in forming an astronomical class, the members of which gave evidence at the annual examination of having benefited well by the lectures as well as by the practical demonstrations in the observatory.

In 1891 Copeland read a paper before the British Association, at its Cardiff meeting, "On the Probable Nature of the Bright Streaks on the Moon" (*Report*, 1891, p. 576). He pointed out that the streaks are only visible when the light falls more or less closely in the line of sight, while they come into view quite regardless of the inclination of the surfaces on which they occur. He concluded that each elementary portion of the streak surface is of a form which is symmetrical to the spectator from whatever point it is seen, a condition which the sphere alone seems to fulfil; and he therefore suggested that the streaks are produced by a material pitted with minute cavities of spherical figure, or strewn over with minute, more or less transparent, solid spheres. To test this hypothesis a plaster model of the Moon was made, on which the bright streaks were represented by lines of minute spherules of transparent glass attached to the surface, which were found to possess the desired property of remaining inconspicuous under cross light, while they flashed out brilliantly when lit up from the front. When suitably illuminated the phases of the model were seen, on photometric examination, to follow a law not very unlike that of the lunar phases found by Zöllner. The short note on this subject does not seem to have attracted much attention; it was to have been followed by a more detailed memoir, which, through press of other work, was never written.

While the new Observatory was being planned and erected Copeland had, of course, only the resources of the old Observatory

on the Calton Hill at his disposal; and he was therefore, to his regret, only able to a limited extent to observe the new star of 1892 in *Auriga* on its first appearance (*Trans. R. S. Edinb.* vol. xxxvii. p. 51), though he had the pleasure, on its reappearance in the autumn, of studying its spectrum at Dun Echt, where the 15-inch refractor had not yet been dismounted. But he took the opportunity offered by this transition period to make arrangements for a new reduction of Henderson's meridian observations, in connexion with which he paid a visit to Berlin in 1893 to consult Professor Auwers on various points. The work turned out to be much more considerable than anticipated; from 1896 it has been carried on by Dr. Halm, and at Copeland's death the printing of the resulting star catalogue for 1840 had not yet been completed. His holidays, whether spent at Dun Echt or elsewhere, often merely meant a change of work, as when he, in the summer of 1894, travelled about the west of Scotland and the north and east of Ireland in order to interview people who had seen a brilliant meteor which, on the 18th of May, at 8 P.M. (in broad daylight), had passed from N.W. to S.E. He succeeded in computing a path agreeing well with the necessarily very rough observations, but his usual wish to postpone the publication of a paper till after repeated applications of the file prevented in this, as in other instances, the publication of his results.

In the meantime the new and stately Royal Observatory on Blackford Hill was approaching completion, the instruments at Dun Echt were dismounted, packed, and forwarded to their new destination, and in May 1895 Copeland took possession of his new home. The unpacking and mounting of the instruments occupied most of that year, so that it was not till April 1896 that the Observatory could be formally opened by the Secretary for Scotland, Lord Balfour of Burleigh, in the presence of Lord Crawford, who gave an interesting account of the origin of the new institution. It might now have been expected that Copeland would have resumed the vigorous activity which he had displayed at Dun Echt, but at that very time it began to be evident that his energy and capacity for work had sensibly declined, and there can be no doubt that the heart disease to which he eventually succumbed had already then commenced to undermine his strength. He never again engaged in any lengthy investigation; still his enthusiasm and love of science induced him to undertake three expeditions to observe total eclipses of the Sun. In 1896 he went to Vadsö, in Finmark, and was (as in 1887) much disappointed at seeing nothing of the eclipse, for which he had made elaborate preparations, bringing with him a 40-foot telescope, with 4-inch Dallmeyer lens, mounted on trestles so as to point exactly to the Sun at mid-totality. He had, however, what to him, as an old Arctic traveller, was the great pleasure of being among the first to greet Nansen on his arrival at Vardö, in the *Windward*.

Undaunted at this second failure, he accepted the invitation of the Joint Permanent Eclipse Committee to take part in the observations of the eclipse of the 22nd of January 1898 in India. He took his 40-foot telescope with him, this time arranged as a horizontal telescope, in which the image was received on 18-inch plates moved by clockwork, while a direct-vision prism, mounted on a slide in front of the object-glass, could be drawn into position by an attendant, transforming the telescope into a prismatic camera. To increase the chances of success he on this occasion selected a station at some distance from other observers, and established himself at Ghoglee, in the Central Provinces, where he was favoured by a cloudless sky. He was equally successful two years later, when he went to Santa Pola, on the south-east coast of Spain, and observed the eclipse of the 28th of May 1900. Of both these expeditions preliminary reports only appeared in the *Proceedings of the Royal Society*, reprinted in the Appendices to the *Monthly Notices*, vols. lviii. and lx.

The first astronomical event of the new century, the appearance of Nova *Persei*, was duly announced in No. 54 of the *Edinburgh Circulars*, which Copeland issued in continuation of the *Dun Echt Circulars*, and that number turned out to be the last one he was to send out, while the spectroscopic examination of the star which he made during the earlier stages of its development was the last astronomical work he was to take part in. In the summer of 1901 he had a severe attack of influenza, from which it may be said that he never recovered. To try to shake off the effects of the illness he went to Wiesbaden in May 1902, but after hurrying to catch a train on the German frontier he was seized with an attack of angina pectoris, which unhappily was but the first of very many similar attacks during the next three years. He had reluctantly to give up his lectures, but he could not give up the hope of still being able to occupy himself with scientific subjects, and, as he was unable to mount the stairs to his beloved "optical room," he made, early in 1904, arrangements for darkening one of the rooms on the ground floor of the Observatory, in order to resume some of the optical experiments of which he had always been so fond. But he was never able to attempt this work. In the spring of 1904 he proposed to retire, but, as the pension offered him was exceedingly small, he was compelled to give up the idea; indeed, for some months in the summer and autumn of that year he was so ill that his death did not seem far distant. Once more his health seemed to improve; after a visit to the seaside in the beginning of 1905 the dreaded attacks ceased in the month of April, and he was tolerably well, though rather weak during the summer. But in the autumn the ordinary symptoms of heart failure appeared, together with other complications, and he passed away peacefully on the morning of the 27th of October, after having been confined to his bed for a little over a fortnight.

Copeland was a man of highly cultured mind, who made

good use of the many opportunities of acquiring knowledge which he enjoyed throughout his life. Even during the last few years he tried to forget his sufferings by taking up the study of Persian, and was delighted to be able to read Omar Khayyam in the original language. His character was open, sincere, and generous, he was always anxious to befriend and help anybody whenever he could, and he never shirked any trouble or work to answer inquiries even from people who had no claim on his time. He will be remembered with warm affection by all who had more than a passing acquaintance with him.

He was elected a Fellow of this Society on the 9th of January 1874.

[The Council are indebted to Dr. J. L. E. Dreyer for the above obituary.]

JOHN DANSKEN was born at Glasgow in 1836, and educated at the Athenæum and Glasgow University. His profession, in which he became well known, was that of a surveyor; in later life he took a considerable share in public affairs, and was placed on the Commission of the Peace for Lanarkshire. He was an enthusiastic amateur astronomer, and built for himself an excellent private observatory containing a 13-inch reflector, several refractors, and a transit instrument. He also formed a valuable collection of astronomical books.

He was elected a Fellow of the Society in 1892, and died suddenly on the 1st of November 1905.

ADAM STOREY FARRAR was born in London in 1826, and educated at Oxford, taking his degree in 1850. At Oxford he won the Arnold prize for history in 1851 and Denyer's theological prize, and was elected to a Fellowship at Queen's College, which he held from 1852 to 1863, holding also a Tutorship at Wadham College for some years. In 1862 he was Bampton Lecturer. In 1863 he married, and shortly afterwards accepted the Professorship of Divinity and Ecclesiastical History in the University of Durham, which he held for forty years. He became a Canon Residentiary of Durham in 1878, and in 1902 was elected to an honorary Fellowship at his old Oxford college.

Astronomy formed but one of many interests which he kept up with undiminishing zeal until his death. It is doubtful if he ever used a telescope, but he was very keen for any observation that could be made with the naked eye. He was moreover an enterprising and critical reader of astronomical works, new and old, and delighted to beguile his leisure by posing his friends with many a crooked question.

He was elected a Fellow of the Society in 1858, and died on the 11th of June 1905.

EDMUND BECKETT, first Baron GRIMTHORPE and fifth Baronet, was born at Carlton Hall, near Newark, on the 12th of May 1816. He was the eldest son of Mr. Edmund Beckett, M.P. for

the West Riding of Yorkshire, who in 1816 had assumed the name of Denison, but reverted to that of Beckett on succeeding to the Baronetcy in 1872. In like manner the subject of this notice, who had the assumed name of Denison, returned to that of Beckett on succeeding to the Baronetcy in 1874. In 1886 he was raised to the Peerage as Baron Grimthorpe with special remainder, in default of male issue, to the heirs male of his father.

Mr. Beckett Denison was educated at Doncaster, Eton, and Trinity College, Cambridge, where he graduated as 30th Wrangler in the Tripos of 1838. He did not, however, make his mark at the University.

He was called to the Bar at Lincoln's Inn in 1841 and joined the Parliamentary Bar, where he practised until 1881. In 1854 he was made Q.C., and in 1877 was appointed Chancellor and Vicar-General of York Diocese and Province.

In his legal career he had a practice rarely equalled, and his income at the Parliamentary Bar for many years was very large. Few men knew more of ecclesiastical law. He was endued with courage and great self-confidence, with a tenacious memory which enabled him to recall the evidence given by a witness years before; and he was merciless in exposing inconsistency.

In 1866 Mr. Beckett Denison published the well-known work *Astronomy without Mathematics*, a singularly lucid and vigorous elementary treatise on the principles of the science, which has passed through many editions.

Of greater importance was his delightful treatise on *Clocks, Watches, and Bells*, which has become a recognised text-book in the watchmaking trade. In this book he is "a clear exponent of other men's work; he suggests improvements and points to future discoveries, and the work breathes the spirit of a man who had touched with his own hands all that he describes." When President of the Horological Society none of its members knew more than he did of the construction of clocks and watches. He was responsible for the design of the Big Ben clock at Westminster, and the credit for that remarkable clock undoubtedly belongs to him.

Lord Grimthorpe strayed into many paths, and all he did was stamped with originality. He was an authority on architectural questions and wrote a book on *Building, Civil and Ecclesiastical*, and there was not a better locksmith in England.

He was a prolific writer and controversialist. His style, though infelicitous and occasionally somewhat involved, was vigorous, caustic, and racy.

He directed the renovation of St. Albans Cathedral, and expended out of his own pocket over 100,000*l*. in its restoration. Besides this he gave munificent assistance towards the restoration of many churches, parsonages, and schools in the country.

In 1845 he married a daughter of the late Bishop Lonsdale, who died in 1901, leaving no issue.

Lord Grimthorpe was elected a Fellow of the Royal Astro-

nomical Society on the 9th of November 1866, and he served on the Council in 1870–3, 1875, and 1878–80.

He latterly lived in retirement at his residence, Batch Wood, St. Albans, where he died on the 29th of April 1905, in his 89th year.

The Rev. SAMUEL JENKINS JOHNSON was the only son of the Rev. S. Johnson, and was born on the 14th of March 1845 at Atherton, in Lancashire, being descended from an old Lancashire family. He early showed a great love for astronomy, and when no more than nine years old began to collect such mentions of celestial phenomena as he could find in the Greek and Latin classics. His great delight at school was to gather his play-fellows in a corner of the playground and give them a lecture on astronomy. He decided to take orders, and with this view he matriculated at St. John's College, Oxford, where he remained for three years, when he took his degree. He was ordained deacon in 1868, and priest in 1869; in 1868 he was licensed to the curacy of West Houghton, Lancashire, and to that of Lytham in 1870. At the end of the latter year he became vicar of Upton Helions, Devon, the church of which he entirely restored. In 1879 he married Miss Mary Drew, and migrated to Abbenhall, Gloucester, where he spent a year in restoring the church; and finally, in 1882, settled at Melplash, Bridport, where the remainder of his life was spent.

Mr. Johnson was elected a Fellow of this Society on the 8th of March 1872, and between that time and the year of his death contributed no fewer than thirty-seven papers to the *Monthly Notices*. These are mostly short notes on ancient and future eclipses, or on his observations of eclipses, transits, occultations, &c. In *Monthly Notices*, vol. liv. p. 142, he published a note on the influence of the full Moon on the weather. His records, kept for fifteen years, appeared to show that there is no ground for the view held by Sir John Herschel, Humboldt, &c., that the full Moon has some effect in dissipating clouds. In 1887 he presented to the Society a large manuscript volume containing particulars of all eclipses visible in England from A.D. 538 to 2500. In 1869 he published a small work, *Eclipses and Transits in Future Years*; he was also the author of *Eclipses Past and Future* (1874) and *Historical and Future Eclipses* (1896). In 1882 he went to Marseilles to observe the transit of *Mercury* of the 6th of December; and in 1900 made a journey to Navalmoral, in Spain, where he successfully observed the total solar eclipse of the 28th of May. He published his observations, with a sketch of the corona, in *Monthly Notices*, vol. lx. p. 590.

Mr. Johnson suffered from gout, and had been for some time failing in health; this became more marked after the death of his wife in 1904. Though scarcely fit for the journey he went to Burgos, where he was successful in observing the total solar eclipse

of the 30th of August 1905. He returned about the 10th of September, and at once resumed his parochial duties. On the 4th of October he attended the Church Congress at Weymouth, but his strength was failing, and he died somewhat suddenly on the 9th of October.

His great interest in astronomy never led him to neglect his work as a clergyman. He made great improvements in his church and parish generally, and was well known among the poor for his kindly interest and warm-hearted generosity. He was attentive to his duties to the last, and only three days before his death had walked three miles over a bad road to the end of his parish. He leaves a son and a daughter, to the former of whom (Mr. S. T. Johnson) the Council are indebted for most of the particulars given in this notice.

Mr. Johnson left a small sum in trust, the income to be devoted to the continuation in various almanacs of his predictions and diagrams of eclipses and occultations.

Charles Jasper Joly was the son of the Rev. J. Swift Joly, of Athlone, and was born in 1864. As a boy at Galway Grammar School he was reputed clever generally, but was not considered to have any special aptitude for the mathematical sciences; indeed it was only as he approached maturity that his remarkable powers became apparent. In 1882 he entered Trinity College, Dublin, taking a scholarship and ultimately the mathematical studentship of his year. From Dublin he went to Berlin, and was for some time a student of experimental physics in the laboratory of Helmholtz and Koenig. In 1887, however, on the death of his father, he returned to Ireland, and read for a Trinity Fellowship, which was attained in 1894. During the years of preparation he acquired a magnificent grasp of Quaternions and of every branch of Mathematical Physics, and almost immediately after his election a succession of memoirs, broken only by his death, showed his masterly power as an investigator.

In 1897 he succeeded Dr. Rambaut as Andrews Professor of Astronomy in the University of Dublin and Royal Astronomer of Ireland; he was elected a Fellow of the Royal Astronomical Society in 1898, and took part in the successful Spanish eclipse expedition of 1900, which was sent out by the Royal Dublin Society and the Royal Irish Academy. But his time during the four years succeeding his appointment was chiefly occupied in the gigantic task of preparing a new edition of the work on Quaternions of his great predecessor, Hamilton. A large amount of additional matter was contributed by Joly himself, and the publication of the first volume in 1899 and the second volume in 1901 created a notable revival of interest in quaternion analysis; this was further stimulated by his own subsequent investigations, especially a memoir on *Quaternions and Projective Geometry*, which occupies over 100 pages in the *Phil. Trans.* of 1903.

In 1902 Joly became Secretary of the Royal Irish Academy, and brought out a new edition of Preston's *Theory of Light*. In 1904 he was elected a Fellow of the Royal Society, and in 1905 a *Manual of Quaternions* appeared from his pen, in which the Hamiltonian manner of establishing the laws of Quaternions is replaced by one leading much more easily and directly to the desired goal.

Joly took a considerable part in scientific life in Ireland; he was a member of the Council of the Royal Dublin Society, and a Trustee of the National Library of Ireland; at the time of his death he was President of the International Society for the Study of Quaternions. For Trinity College he performed many services, especially in connection with projected reforms.

His knowledge of literature, especially of Dante and Italian literature, was profound; and he excelled in the physical life also, being an excellent mountaineer and a member of the Alpine Club.

His death from fever on the 4th of January, 1906, at the early age of forty-one, is a great loss to science.

He is survived by Mrs. Joly, a daughter of the late R. W. Meade, Esq., and by three children.

THOMAS EDWARD KNIGHTLEY was born in 1824. He adopted the profession of architect and practised in London; amongst his principal works are the new buildings for the Birkbeck Bank and the Queen's Concert Hall, Langham Place. He was district surveyor for Hammersmith for forty years; he held other public appointments, and was on the Court of the Cordwainers' Company. He was elected a Fellow of the Society on the 13th of March 1896, but never took any active part in astronomical work. He died on the 4th of September 1905.

WILLIAM ROBERT MAURICE WAUGH, a Congregational minister who throughout his long life was deeply interested in astronomy, was born the 25th of July 1818 in London. His observational work related chiefly to the planets, especially *Jupiter*; but he took much interest in other astronomical work, particularly observations of star colours, and he was for a long period the director of the Coloured Star Section of the Liverpool Astronomical Society, a society which he joined in 1887. His knowledge of all branches of astronomy, and of most branches of physics, was very extensive, and he was an excellent lecturer on scientific subjects. He was for several years Director of the *Jupiter* Section of the British Astronomical Association, and his own observations formed an important part of the work recorded in the Memoirs of that section. He was an excellent draughtsman, and his drawings of *Jupiter* were marked by great accuracy of detail and delicacy of finish. He contributed the additional matter on *Jupiter* to the fourth edition of Webb's *Celestial Objects*. His observatory at Portland, Dorset, contained a

$12\frac{1}{2}$-inch reflector and a $4\frac{1}{2}$-inch refractor, mounted equatorially.

Mr. Waugh was elected a Fellow of the Society in 1888, and died the 25th of November 1905.

Sir William James Lloyd Wharton was born in London in 1843, the son of Mr. R. Wharton, County Court Judge of York, and entered the Navy at the age of 14. In 1865 he became lieutenant, and in 1872 commander, being appointed to surveying service in the Mediterranean and the East African coast; an investigation of currents in the Bosphorus which followed brought him to notice as a scientific officer, and his authorship of the standard work on *Hydrographical Surveying* led to his appointment in 1884 to the office of Hydrographer to the Admiralty, which he held until failing health compelled his retirement in 1904. He was elected a Fellow of the Royal Astronomical Society in 1877, and of the Royal Society in 1886, and served for many years as one of the representatives of the Royal Society on the Joint Permanent Eclipse Committee. In 1895 he was promoted to the rank of rear-admiral (retired), and in 1897 received the honour of a K.C.B.

Sir William Wharton's interest in astronomy was manifested by the persistent exercise of his influence with the Board of Admiralty towards obtaining from time to time accession to the means and appliances of the Royal Observatories at Greenwich and the Cape of Good Hope.

He observed successfully the transit of *Venus* in 1874 at Rodriguez, and again in 1882 in the Straits of Magellan; whilst the skill with which he observed with sextant and artificial horizon renders the numerous astronomical positions determined by him in many parts of the world unchallengeable for their accuracy.

He died at the Cape Observatory while staying there as the guest of Sir David Gill during the visit of the British Association to S. Africa. Lady Wharton and several children survive him.

Otto Wilhelm von Struve was born on the 7th of May 1819 at Dorpat. When he was a child seven years of age the Gold Medal of the Royal Astronomical Society was awarded to his father, Wilhelm Struve, who was Director of the Dorpat Observatory—an honour destined in after years to be conferred on himself, and, in the still more distant future, on his son.

His official connection with astronomy began in 1837, when he commenced to serve as assistant to his father in double-star work at the observatory; at the time he was still a student at the university. Meanwhile the Russian Government, guided by the elder Struve, had established the national Russian Observatory at Pulkowa; and, soon after taking his degree, Otto Struve was appointed, with C. A. F. Peters, to the office of Assistant Astronomer there. His energies were now devoted chiefly to

fundamental determinations; using 400 stars, of which the majority were double stars observed by his father at Dorpat, he undertook an exhaustive investigation on the constant of precession and the proper motion of the solar system. The results were communicated to the Academy of St. Petersburg in November 1841, and printed in their Transactions. This memoir furnished the occasion of the Royal Astronomical Society's award of their Gold Medal in 1850, the author having been elected an Associate two years previously.

In 1852 he became a member of the St. Petersburg Academy of Sciences, and in 1862 succeeded his father as Director of the Pulkowa Observatory, with which institution his whole scientific life is identified. His work centred now, as before, chiefly on double stars and fundamental astronomy; but he took the greatest interest in geodetical investigations, and as consulting astronomer to the general staff and to the hydrographical department he was the chief adviser of the Russian Government in matters related to astronomy and geodesy. Co-operative enterprises found in him a zealous promoter, and with the great Zone Catalogue of the Astronomische Gesellschaft his name will always be associated.

The double stars of Otto Struve were naturally of a more difficult class than those of his father, the instruments being respectively a 15-inch and a 9·6-inch. The measures were collected and discussed by Professor Hussey in 1900. One of his stars, δ *Equulei*, has the shortest period (5·7 years) of any known visual binary. An interesting feature of Struve's work was his unusually large personal equation in the measurement of position angles of double stars; by experiments with artificial stars he was enabled to deduce satisfactory formulæ for correction.

A discussion of the measures of *Saturn's* rings, in which he introduced the nomenclature now used, led him to the conclusion that the inner ring is approaching the planet. This has not been confirmed by more recent measures.

In 1873 he was elected a Foreign Member of the Royal Society.

In 1889, on the fiftieth anniversary of the foundation of Pulkowa Observatory, he retired from the directorship, to which Bredichin was then appointed. The remainder of his life was spent at St. Petersburg, and latterly at Karlsruhe.

Struve died on the 14th of January 1905. He had been twice married, but his second wife predeceased him by some years. The astronomical tradition of the Struve family is worthily maintained by his son, Dr. Hermann Struve, who is an Associate and Gold Medallist of the Society.

Pietro Tacchini was born in 1838 at Modena. He graduated as a prizeman in Engineering at the Academy of Modena, and afterwards studied astronomy at the Observatory of Padua. At the early age of twenty-one years he was called to take

charge of the Observatory of his native city, but four years later left this position on being appointed to the staff of the Palermo Observatory. In 1879 he became Director of the Observatory of the Roman College and of the Central Bureau of Meteorology, and in this office he was for many years one of the central figures in Italian astronomy and spectroscopy. His principal interest was in solar physics; observations of the Sun were carried on regularly during practically the whole period of his scientific activity, and for thirty years he organised Italian eclipse expeditions as opportunity offered. He was one of the chief founders of the Società degli Spettroscopisti Italiani in 1872, and edited its *Memorie*, in which much of his own work was published.

In 1873, writing on the connection between solar prominences and the Aurora Borealis, he stated that the relationship was closer between these phenomena than between Sun-spots and the Aurora.

In 1874 he observed the transit of *Venus* in Bengal, and from his spectroscopic investigations inferred the existence on *Venus* of an atmosphere similar to our own.

In 1883 he went with Janssen to Caroline Island to observe the total solar eclipse, and made the discovery of *white* prominences; this was confirmed in the 1886 eclipse, when Tacchini observed a white prominence 150,000 miles in height.

He was elected an Associate of the Royal Astronomical Society in 1883, and was awarded the Rumford Medal of the Royal Society in 1888. In 1891 he was elected a Foreign Member of the Royal Society, and in the following year received the Janssen Medal of the Paris Academy.

His work as Director of the Meteorological Bureau was carried on with great activity, and to him is due the establishment of the Italian forecasting service.

Tacchini died at Spilamberto, in the province of Modena, on the 24th of March 1905.

Proceedings of Observatories.

Royal Observatory, Greenwich.
(*Director, Sir William Christie, K.C.B., Astronomer-Royal.*)

Transit Circle.—During the year 11,405 observations of transits and 10,057 of meridian zenith distances have been obtained. The Sun has been observed 152 times and the Moon 115 times. The lunar crater Mösting A has also been observed 21 times. Reflexion observations of stars have been obtained on 75 nights. The observations of transits and zenith distances are completely reduced.

The observations for the Second Nine-Year Catalogue are completed. This catalogue will consist of two parts—(I.) Fundamental and zodiacal stars; (II.) Reference stars for the Astrographic Catalogue. Part I. will contain clock stars, polars, fundamental stars contained in the *Nautical Almanac* and other ephemerides, and 834 zodiacal stars given in the Appendix to the *N.A.* for 1897. Part II., which will be arranged in zones 1° wide, contains 10,050 stars. With only seven exceptions, five observations have been obtained of each of these stars, while six of the remainder have been observed four times each, and the seventh (*R Draconis*) is a variable star which has been observed three times, having been too faint for observation on other occasions.

From a comparison of the right ascensions observed above and below pole of the 1400 stars within 10° of the pole, it appears that the probable error of a star's position in this catalogue will be between $\pm 0''\cdot 20$ and $\pm 0''\cdot 25$ in arc of a great circle.

This catalogue furnishes a large amount of material for the determination of proper motions; in particular the comparison with Carrington's Catalogue for 1855 should be of great value.

The reductions for the catalogue are well advanced. The right ascensions of the clock stars and polars have already been determined, and the comparison made with the 12-hour groups. The positions of clock stars for 1906 will be based on the observations of the new catalogue. With the exception of the observations made in 1905—to which corrections for variation of latitude have yet to be applied—the annual results are entered on the catalogue sheets. Precessions and secular variations are all computed.

For the next Nine-Year Catalogue it is proposed to observe all the reference stars down to $9^{m}\cdot 0$ in the Oxford Astrographic Zone, *i.e.* between the limits of 24° and 32° of north declination.

In view of the completion of one catalogue and commencement of another, observations have been made for pivot error and for the errors of the screws of the transit and zenith distance micrometers and of the microscopes. The object-glass has been removed to be cleaned and re-polished, and the instrument is being generally overhauled.

As a result of the re-reduction of Groombridge's observations now completed, Messrs. Dyson and Thackeray have discussed the proper motions derived from Groombridge's Catalogue compared with modern Greenwich observations and have deduced the value of the constant of precession and the direction of the solar motion in space (*M.N.* vol. lxv. p. 428).

Mr. Cowell's analysis of the Greenwich lunar observations 1750–1901 has now been completed by the discussion of the Moon's latitude from the Greenwich meridian observations 1847–1901, and he has deduced the coefficients for a hundred terms in latitude.

In connection with this work Mr. Cowell has discussed the data given by ancient solar and lunar eclipses, and has deduced important conclusions in relation to the secular accelerations of the Moon and Earth (*M.N.* vol. lxv. p. 867, and vol. lxvi. pp. 3–7).

Altazimuth.—This instrument has been used as a reversible transit-circle for observation of the Sun, Moon, planets, and fundamental stars, 1326 observations of right ascension and 1179 of north polar distance being obtained. The crater Mösting A has been observed 41 times. The observations of transits of this crater will serve to connect the observations of first and second limbs made before and after full respectively, and the observations of zenith distances will, in combination with similar observations being made at the Cape, serve to determine the parallax of the Moon.

In the first and last quarters the instrument has been regularly used for extra-meridian observations of the Moon. During the year 34 extra-meridian observations of the Moon have been obtained, and 67 meridian observations of the limbs.

Reflex Zenith Tube.—During the year 799 double observations and 30 single observations have been obtained, the brighter stars having been observed over as long periods as possible. γ *Draconis* was observed on 62 days, β *Draconis* on 40 days, ι^2 *Cygni* on 41 days and θ *Ursæ Majoris* on 23 days. The observations are completely reduced to 1905 October 31, and copy for press prepared to 1905 August 4. Ledgers of the observations from 1902 to 1904 December 31 have been prepared. The hitherto unpublished observations made from 1886 to 1899 have been prepared for press and will be printed as an appendix to the volume for 1904, with a brief summary of the observations made from 1883 to 1885 to discover a possible temperature effect in the observations.

Q 2

Equatorials.—Fifty-one separate occultation phenomena of disappearance or reappearance have been observed by one or more observers.

28-*inch Refractor.*—As in 1904 the weather has been unfavourable for the observation of close and difficult double-stars, and in the absence of the good definition required for these stars, the measurement has been continued of those stars of Struve's Mensuræ Micrometricæ which have been neglected.

An analysis of the observations gives:

46	stars of	distance	<0″·5
57	"	"	0″·5–1″·0
81	"	"	1″·0–2″·0
249	"	"	>2″·0

Amongst the stars observed are κ *Pegasi* (10 nights), δ *Equulei* (13 nights), 70 *Ophiuchi* (12 nights), and *Procyon* (1 night).

The following table gives an analysis of the stars observed since the beginning of double-star observing at the Observatory in 1893:—

Separation.

	<1″.	1″–3″.	3″–5″.	>5″.		<1″.	1″–3″.	3″–5″.	>5″.
1893	38	56	14	13	1900	215	113	19	23
1894	8	9	2	2	1901	226	125	22	34
1895	60	52	12	21	1902	166	114	21	32
1896	106	78	14	23	1903	195	135	40	72
1897	125	78	13	21	1904	140	200	91	189
1898	137	96	21	35	1905	103	134	65	131
1899	260	174	32	68					

The stars originally selected for observation were those with orbital or suspected orbital motion, and were chosen principally from the Catalogues of Struve, Otto Struve and Burnham, and a smaller number from Hough. For 1906 a new working catalogue has been prepared containing most of the double-stars discovered by Hough together with a number taken from the Catalogues of Struve, Otto Struve, Burnham, Hussey and Aitken.

Thompson Equatorial.—With the 26-inch refractor 51 photographs of *Neptune* and its satellite have been obtained on 25 nights.

With the 30-inch reflector a series of photographs of the sixth and seventh satellites of *Jupiter* was begun on August 23 and is still being continued. Up to December 31, 46 photographs of *J.* vi. had been obtained on 25 nights, and 15 of *J.* vii. on

12 nights. Photographs of comets have been taken in the year 1905 as follows:—

Comet *e*, 1904,	11	photographs on	11	nights
Comet *a*, 1904,	12	„ „	11	„
Comet *a*, 1905,	12	„ „	10	„
Comet *b*, 1905,	12	„ „	7	„
Comet *c*, 1905,	5	„ „	3	„

75 photographs of 31 minor planets have also been taken.

These photographs are all taken for determination of position.

A few photographs of nebulæ have also been taken, of which the most successful is one of H V. 14 *Cygni*, with an exposure of 105^{m}.

As regards the measurement of photographs and reductions, the first half of the year was taken up with the 198 astrographic and 152 Thompson photographs of *Eros*. These were completed and the results sent to M. Loewy on August 3.

The results of preliminary measures of *J.* vi. and *J.* vii. were communicated to the Society in November. A more complete measurement and discussion of these photographs has been begun.

The photographs of *Neptune* and its satellite are measured and discussed as far as the end of the last opposition.

Owing to the *Eros* work, the measurement and reduction of the photographs of comets and minor planets had fallen into arrears since 1903. The comet photographs have all been measured with the exception of 1905 *c*, which is still under observation. The results have been published for Comets 1902 *d*, 1903 *a*, 1904 *b* (Encke), and 1905 *c*, and considerable progress has been made with Comets 1903 *c*, 1904 *a*, 1904 *e*, and 1905 *a*. The measurement and reduction of the photographs of minor planets have been commenced.

Experimental photographs of spectra of Sun-spots were taken last autumn with the spectroscope attached to the 30-inch reflector, a diffraction grating being used in conjunction with a direct-vision half-prism to give an extended scale for measurement of the widening of Fraunhofer lines. It is proposed to take further photographs under improved conditions in the spring, when the Sun's altitude will be again sufficient for the purpose.

Astrographic Equatorial.—Work with this instrument has been in the main confined to replacing chart-plates, which, though satisfactory in other respects, are, owing to slight photographic defects, unsuitable for production of enlarged prints. During the year 115 chart-plates, 13 catalogue-plates, 13 plates of the field round *Jupiter*, and 12 plates for adjustment of the instrument have been taken. Of the chart-plates 27 were rejected, principally because they did not come up to the standard in showing faint stars.

The measurement of the photographs was completed by May 10, the total number of plates measured in the year being 22, containing 9550 pairs of images. Since May 10 remeasures of discordant observations in Zones 80°–84° and of some additional reference stars (outside the ordinary limits of measurement) have been made, completing the work as far as Dec. 85°.

The measures of half of Zone 74° and of Zones 75°–79°, covering 438 square degrees, have been printed during the year. The measures are now printed as far as Dec. 80° and occupy 663 pages of vol. ii.; the remainder, covering 310 square degrees, will probably be printed in about half a year's time, and will thus complete this part of the Greenwich Section of the Astrographic Catalogue. Copy for press is prepared for Zones 80°–83°, and the computations for Zones 84°–86° are in hand.

The counting of the chart-plates is now complete to the end of Zone 77°, 267 plates having been counted during the year.

Enlarged reproductions of the chart-plates have been made for 198 plates during the year. The total reproduced to December 31 is 325 plates, the three Zones 65°, 66°, and 67° being complete, and Zones 68°, 69°, 70° nearly half finished.

Photoheliograph.—Photographs of the Sun have been taken on 173 days with the Thompson (9-inch) photoheliograph, and on 51 days with the Dallmeyer (4-inch) during the time that the Thompson photoheliograph was dismounted for use in the eclipse expedition to Sfax, Tunisia. Of the photographs taken 541 have been selected for preservation. Photographs have been received through the Solar Physics Committee from Dehra Dûn, India, up to 1905 December 13, and these have been further supplemented by photographs from the Royal Alfred Observatory, Mauritius, and from the Observatory at Kodaikánal, India. In all only two days are still unrepresented in the year ending 1905 December 13, and one of these will probably be eventually supplied. The last photograph received from Kodaikánal is dated 1905 September 26, and the last from Mauritius 1905 June 30. The photographs from these two observatories are all measured, those from Dehra Dûn are measured up to 1905 November 26, and those taken at Greenwich to 1905 October 19. The increase of solar activity during the year has been very marked, and the work of measurement in consequence has been very heavy.

Some years ago solar photographs were received from the Observatories of Harvard College and of Melbourne, to supplement those of the Greenwich series for the years 1874 to 1877. The reduction of these measures has been completed during the past year; and the results, combined with those from the measures of the Greenwich photographs, have been passed for press, in the form both of a daily register of the Sun's surface and of a ledger of the spot-groups. The ledger of spot-groups for the eight years 1878 to 1885 is also being prepared for press, and it is

intended to publish the results for the whole twelve years as an appendix to the Greenwich results for 1904.

The photoheliographic results for 1904 have been passed for press.

Eclipse Expedition.—Funds having been provided by the Admiralty, a party consisting of the Astronomer-Royal, Mr. Dyson, and Mr. Davidson went out from the Royal Observatory to Sfax in Tunisia to observe the solar eclipse of August 30. They were generously assisted in the work by Professor Sampson, Mr. J. J. Atkinson, and Captain Brett, and successful photographs of the Corona and its spectrum were obtained. A preliminary account of the observations was given at a joint meeting of the Royal and Royal Astronomical Societies on October 19, and is printed in the *Proceedings of the Royal Society*, vol. lxxvii.

At the invitation of the Canadian Government, Mr. Maunder joined their party in Labrador for observation of the eclipse; but unfortunately, owing to cloudy weather, no results were secured.

Printing.—The volumes of Greenwich Observations 1903, and the New Reduction of Groombridge's Catalogue are ready and will be distributed shortly, together with the volume of Longitude Determinations, 1888–1902, which is printed and now being bound. The printing of the volume for 1904 is approaching completion. The Heliographic Results 1874–1885, completed from photographs supplementing the Greenwich series, are being printed as a special publication, and the printing is completed to the end of 1877. The printing of vol. ii. of the *Astrographic Catalogue*, which completes the measures of the Greenwich section, is finished as far as Zone 79°, more than five-sixths of the whole being thus done.

The Observatory has lost the valuable services of Mr. Dyson, who resigned his post as Chief Assistant on his appointment as Astronomer-Royal for Scotland and Professor of Astronomy in Edinburgh University. His resignation took effect on 1906 January 13, just after the date of this report.

Royal Observatory, Cape of Good Hope.
(Director, Sir David Gill, K.C.B., H.M. Astronomer.)

The new transit circle has been in active operation during the year, the transits having been observed by the Repsold travelling wire method and without clockwork to aid the observer.

Experiments, however, have been made with the cone apparatus constructed by the Société Génevoise to the designs of H.M. Astronomer, but the method has not yet been brought into regular use, as the original motor, employed to rotate the cone, required modification to give perfect results. The cone

apparatus itself works to perfection, but it was found undesirable to apply the observer's fingers to the revolving drum of the micrometer, and the improved motor will be provided with differential gear like that employed on the driving gear of an astrographic equatorial, so that the motion of the wire can be accelerated or retarded by simply touching one of two keys held in the observer's hand, and without touching the revolving micrometer drum. The transit circle was reversed on its bearings every Monday morning, and the object glass and eye-end were exchanged at the conclusion of the observations of 1905.

The outer chamber enclosing the case of the new sidereal clock has been completed and has proved most successful. The temperature within the clock-case is now maintained constantly at 75° F. within a tenth of a degree F.

Some trouble has been given by demagnetisation of the polarised armature of the magnet which discharges the pendulum of the slave clock, but this difficulty seems now to have been overcome.

The driving sector of the Victoria Telescope, which had been sent for repair to Sir Howard Grubb early in November 1904, was received in April 1905, together with a "quick slow-motion" in R.A. devised by him, which is of great convenience for rapidly bringing a star on the slit of the spectroscope. The instrument was brought into use on May 4.

Some desirable changes had to be made on the spectroscope; these occupied a long time, as only one mechanic is available and his time was much taken up in connection with the transit circle, the mounting of the underground object-glasses, &c.

The Victoria Telescope was devoted to the photographing of star clusters and nebulæ, and photographic observations of the satellites of *Uranus* and *Saturn*. A number of good photographs of *Phœbe* have been secured. An unsuccessful search was made on six nights for Comet Tempel III.; Comet *b* 1905 was observed on two nights. Fifty-four star-spectra have been measured and discussed for motion in the line of sight.

The object-glasses for use in the collimator pits of the new reversible transit circle have at last been received of the requisite foci and good definition; they are now mounted and have been under observation since October 31.

It is found that by their means the reflex images of very small illuminated discs (attached to the slides that carry the lenses of 300 feet focus and the marks in focus of these lenses) can be adjusted by a single pointing to coincidence with a wire fixed on the same slides, with a probable error of less than $\pm 0{\cdot}005$ mm., so that the probable error in this adjustment of the points of azimuth-reference barely exceeds $0''{\cdot}01$.

The marks, when so adjusted, retain a perfectly constant relative azimuth far within the probable error of their observation with the transit circle; but without adjustment over the optical centres of the underground object-glasses there would be

comparatively large variations of azimuth, as is proved by the readings of the scales attached to the slides. In the case of the south marks this reading has changed with a steady increase by 1·47 mm. between October 31 and December 31, that of the north mark by 0·99 mm. in the same period. The readings of the scales, which carry the long focus lenses, are much more constant, the extreme readings having varied only 0·07 mm. for the north lens and 0·08 mm. for the south lens in the same period.

The reductions of the observations of Circumpolar Stars are not yet sufficiently advanced to determine the absolute azimuth variation of the underground marks. There is evidence, from discussion of the observations of the marks, of a systematic variation of the azimuth of the transit circle itself between sunset and midnight, and always in the same direction, amounting from $0''.3$ to $0''.5$.

The printing of the Cape Catalogue of 8560 stars (Photographic Zone Standards) has been completed. The introduction has been sent to the printers.

The manuscript of separate results of Meridian Observations 1900–04, all reduced to the Equinox 1900, was sent to the printers on 1905 June 20. The sheets have been passed for press to R.A. 19^h.

The manuscript of the Catalogue of 4360 stars, including 2798 selected zodiacal stars and all stars brighter than 8·1 magnitude which are not contained in Gould's General Catalogue (excepting those in the zone $-40°$ to $-52°$, most of which are included in the Astrographic Standard Catalogue), has been sent to the printer and some of the first sheets passed for press.

The manuscript of the Solar and Planetary Meridian Observations 1884–92 is ready for the printer.

The manuscript of vol. x. of the *Annals*, containing researches by Mr. Lunt on the spectra of silicon and fluorine, has been sent to the printer.

The printing of part ii. vol. xii. of the *Annals*, containing Mr. Cookson's observations with the heliometer of the relative distances and position angles of *Jupiter's* satellites, and his derivation from them of the mass of *Jupiter* and of the inequalities of the motions of the satellites, is nearly completed.

The manuscript of the results of the heliometer observations of major planets from 1897 to 1904 is nearly ready for the printer.

The old transit circle has been employed at the urgent request of Professor Boss to determine the positions of 1154 stars south of Dec. $-36°$, of which he is specially desirous to obtain observations in connection with the completion of his Standard Catalogue. Stars of which occultations have been observed or which have been employed for latitude determination in connection with the geodetic survey are also included in the working list with the old transit circle.

The new reversible transit circle has been devoted to the observation of standard stars.

In co-operation with the Royal Observatory, Greenwich, the zenith distance of the Moon has been observed with both transit circles for determination of lunar parallax.

The following observations have been secured :—

	Old T.C.	Reversible T.C.
Number of transits	2679	4199
Determinations of z. d.	1718	4236
Collimation, by collimators	64	24
„ „ reflection and reversal	0	42
Level	225	364
Azimuth	252	433
Observations of azimuth marks N. ...	0	298
„ „ „ S. ...	0	293

These observations include 51 observations of the lunar crater Mösting A made with the old transit circle and 25 with the new reversible transit circle.

Of occultations there have been observed :—

Disappearances at the dark limb	15
Reappearances „ „ „	4
„ „ bright limb	1
	20

The following oppositions of major planets have been observed with the heliometer during the year :—

	No. of Observations.	No. of Nights.
Opposition of *Mars*	48	4
„ „ *Uranus*	60	6
„ „ *Saturn*	43	7
„ „ *Jupiter*	51	8
„ „ *Neptune**	20	3

The following heliometer observations have been made during the year in connection with the triangulations of the comparison stars :—

	Observations.
Neptune 1897–1904, *Jupiter* 1906	122
Mars 1899...	110
Mars 1905...	74
Uranus 1898–1902	22
Jupiter and *Saturn* 1901...	29
Jupiter 1902, *Saturn* 1903	36
Saturn 1902	40
Jupiter 1904	42

* Still under observation.

The triangulations of the comparison stars for *Neptune* 1897–1904, *Jupiter* 1906, *Uranus* 1901–2, *Jupiter* and *Saturn* 1901, *Mars* 1899, and *Jupiter* 1904 are now completed.

A special series of observations with the heliometer was made by Mr. Bryan Cookson during the visit of the British Association to South Africa, to determine whether, in his measurements, distances like those mutual distances of *Jupiter's* satellites which chiefly enter into the determination of the mass of *Jupiter* have any systematic error when compared with distances like those of the standard stars employed for determining the scale value. For this purpose sets of three stars were selected, such that in each set the three stars lie nearly on the same great circle at distances varying in proportion from about 1 : 7 to 1 : 14. If the sum of the two measured distances when projected on the great circle joining the extreme stars (about 110′) is equal to that of the distance measured directly between the two extreme stars, then the systematic error of the measured distances on which the determination of the mass of *Jupiter* depends should be zero—or at least should be affected by no "distortion error."

Mr. Cookson secured 302 observations of this kind. The position angles of these stars (227 observations) were measured by Mr. Whittingdale after Mr. Cookson's departure for England, and the results show that Mr. Cookson's measures of distances from about 500 "to 1000" are not affected by any sensible systematic error.

With the astrographic telescope the following work has been accomplished:—

	No. of Plates.	No. of Exposures.	Duration of Exposure.
			m m m
Triple exposure chart plates, passed ...	77	231	20 20 20
" " " " rejected...	5	15	20 20 20
			m
Single exposure chart plates, passed ...	85	85	30
" " " " rejected...	3	3	30
			m m s
Catalogue plates, second series, passed	188	564	6 3 20
" " " " rejected	44	132	6 3 20
Adjustment plates	19	...	various
Plates for Mr. de Sitter *	13	52	1^m and trail
Miscellaneous †...	10	...	various

* Taken in connection with discussion of photographs of *Jupiter's* satellites 1904.

† The miscellaneous plates include 5 plates near *Jupiter*, 2 plates of region near Comet *b* 1905, and 2 plates of occulted stars.

The following table gives the work done in connection with the Astrographic Chart and Catalogue to the end of 1905 :—

Dec. of Centre of Zone.	Triple Image Charts. Taken.	To be Taken.	Single Image Charts. Taken.	To be Taken.	Second Series Catalogue Plates. Taken.	To be Taken.
41°	143	1	...	...	144	0
42	...	...	142	2	144	0
43	144	0	...	...	143	1
44	...	...	140	4	144	0
45	143	1	...	...	143	1
46	...	...	143	1	143	1
47	144	0	...	...	143	1
48	...	...	142	2	144	0
49	118	2	...	...	119	1
50	...	...	119	1	120	0
51	119	1	...	...	120	...
52	...	...	65	55	...	...

During the year 148 Catalogue plates, containing images of 1944 standard and 112,086 other stars, have been measured ; all stars have been measured in reversed positions of each plate, and all standard stars have in addition been measured by two observers. Besides these 16 plates of the first Catalogue series were measured for Professor Kapteyn, for purposes which were the result of some discussions with him at the Cape on the occasion of the visit of the British Association.

The actual state of measurement on December 31 is as follows :—

Zone.	No. of Plates Measured. Before 1905.	During 1905.	Un-measured.	Copied for Press. Before 1905.	During 1905.	Out-standing.
−41°	144	...	...	144	...	0
−42	137	7	...	128	16	0
−43	139	3	2	70	45	29
−44	118	14	12	43	24	77
−45	108	30	6	18	1	125
−46	71	42	31	2	1	141
−47	24	41	79	0	2	142
−48	18	7	119	4	1	139
−49	0	1	119	0	1	119
−50	0	3	117	0	3	117
−51	0	0	120	0	0	120
Totals	759	148	605	409	94	1009

The total number of measured plates is now 907, containing

over 550,000 star images, corresponding to about 251,000 different stars.

The constants for zones whose centres are $-41°$ and $-42°$ have been computed, and also for 104 plates of zone $-43°$, for 16 plates of zone $-44°$, and 19 plates of zone $-45°$.

Colonel Morris reports that the field work of the principal triangulation of the Transvaal and Orange River Colony is now completed. It is expected that the reduction of the observations will be finished by the end of 1906. A detailed account of the work was presented in a Report to Section A of the British Association and will be published in full in the British Association Report of the 1905 meeting.

The latest Report of the Geodetic Survey of Rhodesia from Dr. Rubin gives copies of field work up to 1905 August 5, and shows that stations up to latitude $-13° 58'$ have been observed.

The Report of the Anglo-German Boundary Commission has been completed and sent to press.

Longitude of Accra.—Signals for longitude were exchanged, through the West Coast cable, on five nights in February 1905, between Mr. R. T. Pett at the Cape and Major (now Lieut.-Col.) A. E. Watherston, C.M.G., R.E., at Accra. Good time determinations were obtained on four of these nights. The following are the results for longitude :—

	h m s	s
Accra, W. of Cape T. C.	1 14 44·309	±0·019
Cape T. C., E. of Greenwich ...	1 13 54·757	±0·084
Accra, W. of Greenwich	0 0 49·552	±0·086

Current time, $1^s·48$; length of cable, 3648 knots.

Longitude of Swakopmund.—Two German military officers, Captain Füsslein and Ober-Leutnant von Stephani, who were engaged upon the determination of the longitude of Swakopmund, were provided with accommodation for their instruments at this Observatory.

Longitude of St. Helena.—With the concurrence of the hydrographer and the kind co-operation of the Union-Castle S.S. Company, who carried the travelling observer to and from St. Helena free of charge, a telegraphic determination of the longitude of St. Helena was made in September and October by Messrs. Pett and Cox—Mr. Pett at St. Helena and Mr. Cox at this Observatory.

Good time determinations were obtained on six nights. The resulting longitude is as follows :—

	h m s	s
Johnson's Observatory, W. of Cape Transit Circle	1 36 48·022	±0·023
Cape T. C., E. of Greenwich ...	1 13 54·757	±0·084
Johnson's Observatory, Ladder Hill, St. Helena, West of Greenwich	0 22 53·265	±0·087

Current time, $0^s·237$; length of cable, 1881 knots.

For all these operations the use of the various cables was freely granted by the Eastern Telegraph Company.

The records of the seismograph have been regularly forwarded to Professor Milne, Secretary to the Seismological Committee of the British Association. A second copy is also forwarded to the Consul-General for Germany, Cape Town for transmission to the central station for investigation of earthquakes at Strassburg.

The meteorological observations have, as usual, been communicated to the Meteorological Commission, Cape Town.

During the visit of the British Association to Cape Town many of the members availed themselves of the opportunity of inspecting the Observatory and its equipment.

Royal Observatory, Edinburgh.
(Director, Prof. F. W. Dyson, Astronomer Royal for Scotland.)

During the past year the Observatory has suffered the loss of its distinguished Director, Professor Ralph Copeland, Ph.D., who died on 1905 October 27. Mr. F. W. Dyson, Chief Assistant at the Royal Observatory, Greenwich, has been appointed to succeed him in the Directorship of the Observatory and in the Chair of Astronomy at the University of Edinburgh.

Meridian Circle.—The observations of zodiacal stars and heliometer comparison stars begun in 1898 have been continued by Mr. Clark throughout the year, with the exception of June and July, when zodiacal work is practically impossible in this latitude. The number of transits observed is 1088 and of zenith distances 907. Occasional observations of the planets have also been made.

15-*inch Equatorial.*—Micrometric observations of the position of Comet 1905 *a* were made on four nights in April, of Comet 1905 *b* on five nights in November, and of Comet 1905 *c* on four nights in December and January.

Spectroscopic Observations of the Rotation of the Sun.—These observations were made as in previous years on all suitable occasions by Dr. Halm. The observations from 1901–1905 have been discussed with the view of discovering the displacements due to the diurnal and annual motions of the observer with very satisfactory results, the eccentricity of the Earth's orbit, for example, being given within 4 per cent. of its true value. These investigations, which are being published in the *Proceedings* of the Royal Society of Edinburgh, need only be referred to here as evidence of the accuracy of the observations and their freedom from systematic error.

The reduction of the meridian observations has fallen somewhat into arrear. The observations from 1898–1901 have been reduced as far as apparent place, and the reduction to mean place will be completed in a few months. For the years

1902–1905 the chronograph tapes have been read. It is proposed to push on these computations as rapidly as possible.

The printing of Henderson's Catalogue for 1840, re-reduced under the charge of Dr. Halm, is nearly completed. The Introduction has been written but is not yet printed.

Seismographic observations have been made continuously by Mr. Heath and reported to the Seismological Committee of the British Association.

Meteorological observations have been regularly made.

Greenwich mean time has been supplied daily to Edinburgh and Dundee.

Cambridge Observatory (Director, Sir R. S. Ball).

Sheepshanks Equatorial.—During the year 73 plates, each containing four or more exposures, have been taken by Mr. Hinks. The greater part of these are in continuation of the stellar parallax series begun two years ago. A general description of the methods of this research has been published by Mr. Hinks and Mr. Russell (*Monthly Notices*, 1905 June, lxv. 775), and the first results, the parallaxes of Lalande 21185 and γ *Virginis* were published by Mr. Russell at the same time (*Monthly Notices*, lxv. 787).

Mr. Russell left Cambridge in 1905 July, but will continue the measurement and reduction of these plates at Princeton, N.J.

Experiments were made during the year to compare the speeds of various brands of ordinary and isochromatic plates with the photo-visual objective. The result was that the ordinary plate, utilising chiefly the blue and violet rays, was found to be more effective than the colour-sensitive plates, utilising nearly the whole range of photographic and visual rays brought to focus by the photo-visual objective.

Mr. F. J. M. Stratton, B.A. (Caius College: Isaac Newton Student in the University), has recently joined the Observatory as an honorary member of the staff, and has undertaken researches in the determination of the proper motions of faint stars by photography.

Meridian Circle.—The principal work of the year in this department has been the completion by Mr. Hartley of the preparation for press of a large volume of meridian circle results for the years 1872–1900. This volume will contain the results of all the individual observations for the Cambridge zone of the Astronomische Gesellschaft Catalogue, and in addition the results of about 12,000 observations of stars in the zone which were not included in the original programme, but of which a single observation had been made and published in the Zone Catalogue.

Observations of 631 stars in Gill's Zodiacal Star Catalogue

were made by Mr. Hartley on 26 nights, with the necessary observations of fundamental stars and instrumental errors. The reductions to apparent place are complete to 1905 July 31; and the reductions to mean place to 1905 June 22.

Floating Zenith Telescope.—Mr. Cookson has continued throughout the year the determination, with his floating zenith telescope, of the Constant of Aberration by Küstner's method, and of the variation of latitude. Observation of the two star groups in 1905 February and March was much interrupted by bad weather, but since then the weather has been fairly good, and at least six observations of each pair of star groups have been obtained. All the plates so far exposed have been measured, the refractions and daily corrections have been computed and checked, and it is expected that it will be possible to deduce a value of the Constant of Aberration from the first year's observation at the end of next April.

Reduction of Photographs of Eros.—The results from the 106 Cambridge photographs which were used in the experimental determination of the solar parallax published in 1904 June have been further reduced to apparent place and compared with the corrected Paris ephemeris. The results of 55 Oxford photographs have been similarly reduced at Cambridge. They will be published in detail in the twelfth Paris *Circular*, now in the press. The introduction to the Cambridge section will contain a brief summary of much work done during the year on the comparison of different ephemerides of the planet.

The discussion of all published photographic places of *repère* and comparison stars, for the investigation of the systematic errors of the different series, and the formation of a catalogue of standard star places, has made good progress, and an account of it is in preparation. Mr. Hinks has been aided in this work throughout the year by Miss Julia Bell, and a portion of the expense has been borne by a Royal Society grant.

Instruction.—Courses of instruction in practical astronomy, and in field astronomy and surveying, have been given by Mr. Hinks during the year.

The Newall Telescope, Cambridge Observatory. (*Mr. H. F. Newall.*)

The Newall Telescope was used for observations on fifty nights in the first half of the year 1905 to June 30; after this date, partly because of change of programme of work and partly for reasons connected with a change of assistant, the record is no longer serviceable for comparison with previous years.

Spectroscopic studies of the stars have been carried on, principally in the determination of velocity in the line of sight. Eighty-seven photographs of stellar spectra, with terrestrial comparison spectra, were obtained by Mr. H. J. Bellamy before he left

the Observatory on June 30 to take up new work at the Royal Naval College at Osborne. In the first quarter of the year the four-prism spectrograph was used for continuation of the photographic study of stellar spectra in the green region of the spectrum. On March 22, when the desired material for these studies was collected, it was readjusted for the region near Hγ, and was used in that adjustment until July 21, when it was dismounted to be packed for use in observations of the total solar eclipse on August 30 at Guelma, in Algeria. It was received back again at the Observatory on September 27, and since that time the prism train has been used by Mr. E. T. Whittaker in the study of the red region of certain terrestrial spectra by photographic methods.

A description of the four-prism spectrograph as used for stellar studies was given in the *Monthly Notices* last year (*M.N.* lxv. 636–650). And the results of determination of velocity for stars observed in 1903, in co-operation with observatories abroad, have also been published (*M.N.* lxv. 651–655); those for 1904 are being prepared for publication.

In the autumn a new grating spectrograph was mounted on the 25-inch equatorial. It was designed (i.) to give serious trial to a comparison of the efficiency of grating and prisms in stellar studies, on the lines indicated in a discussion of the design of large spectrographs (*M.N.* lxv. 608–635), and (ii.) to test the atmospheric conditions at Cambridge for solar work. Up to the present date it has been used only in observations of sun-spot spectra, and a good deal of preliminary work has been done, specially in connection with the study of the relative brightness of (*a*) the spectrum of the umbra of large spots, and (*b*) the spectrum of the glare of the sky close to the limb of the Sun. Fifty-six photographs have been kept for detailed study, out of a great many taken in this connection.

If one may judge by the distinctness with which many of the peculiarities of sun-spot spectra are recorded on the photographs obtained in these unfavourable months, and by the clearness with which the resolution of the spectrum of the umbra into fine lines and bands, as recorded by Young, Dunér and others, has been corroborated on many occasions, these preliminary observations show that the atmospheric conditions at Cambridge for the study of solar phenomena are promising.

Observations of the total eclipse of the Sun on August 30 were successfully made at Guelma under very favourable conditions of weather. A preliminary report upon them was published in the *Proceedings of the Royal Society* (vol. lxxvii. 56–76).

Mr. W. H. Manning began work at the Observatory in June in place of Mr. H. J. Bellamy, who left on June 30.

Dunsink Observatory.

Systematic work with the meridian circle recommenced in October last, when it was decided to re-observe the stars in Part IV. of *Dunsink Observations.* This is a list of 321 red stars by Dr. Dreyer. During the year 1905 the number of observations made with this instrument is 1067, consisting of 357 observations in R.A. of red stars, 170 observations of Berliner Jahrbuch stars for clock correction, 29 determination of level, 28 of collimation, while 23 stars were observed for azimuth errors. In declination 357 observations were made of red stars, 80 stars were observed for the equator point of the circle, 18 determinations were made of the nadir point, and 5 of the error of runs.

The first part of the year was occupied in finishing the reductions of Sir David Gill's zodiacal stars and preparing the work for press; this work is now ready for the printer.

In September a hole was made in a thick pier in the basement of the observatory, and the Dent Sidereal clock was taken from the meridian room and placed there. The temperature in this place is more uniform than the meridian room, the variation in a week being about 1°; the rate of the clock consequently shows a great improvement.

Some photographs were taken with the Roberts telescope, but owing to a slight shift of the mirror during long exposures they are found to be useless.

The South Equatorial has principally been used in showing visitors objects of interest on the first Saturday of each month.

The time service with Dublin has been carried on as usual.

Since the date of this report the death has been announced of Professor C. J. Joly, M.A., Sc.D., F.R.S., Royal Astronomer for Ireland. A notice will be found in the Obituary.

Durham Observatory. (*Director, Professor R. A. Sampson.*)

During the year the almucantar has been used on forty nights, and 619 transits have been observed with it and reduced.

A very large amount of work has been done on the discussion of the Harvard eclipses of *Jupiter's* satellites. The work is now almost complete as far as concerns the derivation of the elliptic elements of the orbits, the chief inequalities of the four satellites, the position of *Jupiter's* equator, the equation of light, and other quantities involved in the theory. When this work has been written out for publication in the Harvard *Annals* it is intended to proceed with the formation of a new theory of the motions based upon the elements determined.

Glasgow Observatory. (Director, Dr. L. Becker.)

The observations of stars close to the Pole were continued with the transit circle during the first four months whenever the sky was sufficiently clear. The spectrograph connected with the 20-inch reflector was principally employed on attempts to photograph the red and yellow portion of the spectra of planets. A series of fairly good negatives of *Jupiter's* spectrum was secured, but it is hoped that with a longer exposure still better results might be obtained. Unfortunately the weather was not more favourable to the experiment than in former years, yielding only twenty-eight hours on six nights from October 1 to December 31.

The site of the observatory has in the course of years become unfit for an observing station. According to regular observations begun four years ago on the distance at which objects can be seen from the Observatory the radius of visibility is, in the four months November to February, less than a mile on 70 per cent. of the occasions, and only on 5 per cent. of the occasions distant hills can be seen. The University Court has at present under consideration a scheme for the removal of the Observatory to a more favourable site outside the range of fog and haze which usually envelop this large manufacturing city.

A preliminary report of the director's solar eclipse expedition to Kalaa-es-Senam, Tunisia, has been published in the *Proceedings of the Royal Society*, A, vol. lxxvii. He successfully employed mechanisms governed by a clock which automatically effected the exposures and the changing of plates.

The time service and meteorological observations have been carried on as in former years.

Liverpool Observatory. (Director, Mr. W. E. Plummer.)

Reference was made in the last Annual Report to the measurement of a photograph of the cluster in *Hercules* taken with the large refractor of the Yerkes Observatory. A measuring machine kindly lent by the Oxford University Observatory has been used for this purpose. The results of the measurement and their discussion have been published in *M.N.* vol. lxv. 801–813, and arrangements are in progress for undertaking new work in the same direction. In addition to the ordinary work, which is carried on with the transit instrument, the equatorial has been employed as continuously as possible in the observation of comets, the results of which appear from time to time in the Society's publications. As in previous years, occasional observations of double stars are made.

The general maintenance of the Observatory is continued as in former years. No alteration is to be reported either in the

permanent staff or in the instrumental equipment. The meteorological and seismological observations are continuously maintained. In connection with the routine work may be mentioned the distribution of time signals, the testing and rating of chronometers, and the examination of sextants and other apparatus, for which the Mersey Docks and Harbour Board is prepared to grant certificates of test. Lectures in connection with the University of Liverpool are regularly given in the Observatory.

Radcliffe Observatory, Oxford.
(Director, Dr. A. A. Rambaut, Radcliffe Observer.)

Systematic work with the transit circle has been discontinued throughout the year, only occasional observations being made with it for the determination of time and instrumental errors. A recomputation of the division errors of the circle as determined in 1881 and 1882 was carried out, and in connection with this work a number of readings of the circle were taken for determining the errors of the four quadrantal lines 0°, 90°, 180°, and 270°. The result of this recomputation was to confirm very closely the division errors found by Stone, which have been used in the reduction of all zenith distance observations since 1880. Advantage was taken of the interruption of work with the transit circle to send the eight microscope-micrometers to Messrs. Troughton & Simms for cleaning and repairs.

The printing of the Catalogue mentioned in former reports has, with the exception of the introduction, been completed during the year. It is hoped that the introduction may be printed and the volume ready for distribution within a few weeks. This Catalogue gives the position of every star down to the seventh magnitude contained in the Zone 85° to 90° N.P.D., with very few exceptions, and these occur only in double or multiple systems. In it will also be found the position of every star in Dr. Downing's Zodiacal List which has not been already included in the Radcliffe Catalogue for 1890, with the exception of one star (D.M. + 27°, 725) whose magnitude, as given in the list, is obviously in error.

The places of the Catalogue have been compared with those of the Radcliffe Catalogue for 1890, the Greenwich Second Ten-Year Catalogue for 1890, Newcomb's Fundamental Catalogue, and the Albany (A.G.) Catalogue, 1875, with very satisfactory results. The probable errors in both co-ordinates are also very small, the probable error of a single observation being only $\pm 0^{s}{\cdot}028 \times$ cosec N.P.D. in R.A., and $\pm 0''{\cdot}32$ in N.P.D.

The Barclay 10-inch equatorial has been used for various purposes, including observations of Mr. Stanley Williams's variable, 159 (1904) *Pegasi*, of Mrs. Fleming's Nova, 104 (1905) *Aquilæ*, the lunar crater *Linné*, and of the solar eclipse of August 29–30.

The new double equatorial has been used during the spring and autumn months for investigating stellar parallax according to the method proposed by Professor Kapteyn (*Bulletin de la Carte du Ciel*, tome i. p. 262). In this work it is essential that the stars should be photographed close to the meridian, and also that the parallax factor should be as large as possible. To ensure these two conditions and at the same time to avoid running into twilight, the star must be observed within comparatively narrow limits of time, so that a spell of unfavourable weather may seriously interfere with the carrying out of the full programme. During the year nine parallax plates have been successfully completed, each containing twelve exposures—three in the first season, six in the second, and three again in the third—with three short additional exposures for identification. Seven plates have been exposed at two seasons—spring and autumn—and will, it is hoped, be completed in the ensuing spring. Sixteen plates have been exposed at only one season.

A number of plates, other than those taken for parallax, have been obtained in the course of the year. These include photographs of the *Pleiades*, *Præsepe*, the great clusters in *Perseus*, and Nova *Aquilæ*, &c., and plates taken for the adjustments of the polar axis, eyepiece scales, &c. The visual 18-inch telescope has been used for observations of Nova *Persei* (January 18 and October 4), Comet (a) 1905, and the lunar crater *Linné*. The partial eclipse of the Sun of August 29–30 was observed with the 7-inch telescope attached to this instrument (see *M.N.* vol. lxvi. 7).

A large number of measures, chiefly of an experimental character, have been made with the new photographic measuring-machine. In this instrument a microscopic *réseau*, optically projected on the plate and movable by two mutually perpendicular micrometer screws, is used for subdividing the 5 mm. spaces of the principal *réseau*. Great difficulty has been experienced in obtaining a *réseau* divided with sufficient accuracy for this purpose, and a considerable proportion of the measures made with the machine have been undertaken for the purpose of testing *réseaux* which have been subsequently discarded.

Meteorological and earth-temperature observations have been carried on as heretofore.

University Observatory, Oxford. (*Director, Prof. H. H. Turner.*)

The negotiations between the Government and the University concerning the printing of the Oxford portion of the *Astrographic Catalogue* were brought to a successful issue by the friendly aid of the Royal Society; and it was arranged last spring that the work should be done by H.M. Stationery Office, the expense being borne by the Government and the University in equal portions. At the request of the Director the commencement of

the printing was delayed until after the eclipse expedition, but as soon as possible after the return of the expedition detailed arrangements were completed, and the first proofs were received before the end of the year. The work of passing this Catalogue through the press will accordingly absorb a large part of the energies of the small staff of this Observatory for the next few years.

An expedition to Aswan, practically the eastern end of the line of totality, to observe the total solar eclipse of August 30 last was successfully carried out, with the able and generous help of Captain H. G. Lyons, Director of the Egyptian Survey, and his officers. The 13-inch astrographic objective was taken out to Aswan and mounted in a temporary tube of gas-piping and cloth, pointed to a 16-inch cœlostat. Mr. F. A. Bellamy obtained excellent photographs of the corona with it; and successful photographs in polarised light were obtained by the method of reflection from a plane glass surface suggested by Professor Schuster, two fine prisms being lent for the purpose by Mrs. McClean. The expedition was joined by Mr. J. H. Reynolds, of Birmingham, who took out to Egypt a reflecting telescope of 120 feet focal length, mounted with a cœlostat mirror of 28 inches aperture. Unfortunately his plates were not successful, in great part owing to the action of the wooden plate holders, which marked them badly with the wood pattern. The reasons why this occurred in this case and not in others are still uncertain, and are being made the subject of investigation.

The staff of the Observatory take pleasure in remembering that they were able to render some assistance to the successful Conference on Co-operation in Solar Research held in Oxford in September last.

Mr. F. H. Scragg, the last of the computers engaged from time to time for the measurement and reduction of the *Astrographic Catalogue* plates, left the Observatory in July last to take up an appointment at the Cape Observatory.

Temple Observatory, Rugby. (*Director, Mr. G. M. Seabroke.*)

The usual routine of instruction has been continued at this Observatory and the attendance has been good. Six boys have attended regularly for instruction in handling the instruments, and three have been sufficiently proficient to be allowed there alone to photograph the Moon and for other purposes. The measurement of doubles has been continued in spare time.

Solar Physics Observatory, South Kensington. (*Director, Sir Norman Lockyer, K.C.B.*)

Observations of Sun-spot Spectra.—The Sun was seen on 241 days during 1905, and observations of sun-spot spectra were made on 125 days, permitting the examination of 268 spots in

the region F—D. The records continue to show that the chief lines affected are due to vanadium, titanium, scandium, and some unknown elements.

Daily photographs (glass negatives) of the Sun's disc are received from Dehra Dûn (India) and Mauritius, the gaps in the Indian record being filled up as far as possible by negatives from Mauritius. The negatives are forwarded to Greenwich for measurement and reduction as they are required. Positives on paper are also received, and these are mounted on cartridge-paper and bound up into half-yearly volumes.

The Spectroheliograph.—The weather conditions were fine enough on 144 days to warrant attempts being made to obtain monochromatic photographs of the Sun. The instrument cannot be used satisfactorily during the winter months on account of its position. During the period 1905 February 2 to November 27 247 negatives were secured showing the distribution of "K" radiation on the Sun's disc; with the addition of an occulting disc over the primary slit-plate, 42 negatives were obtained showing the prominences round the solar limb.

A description of the instrument and details of the methods of working have been communicated to the Society (*Monthly Notices*, vol. lxv. pp. 473–486).

Stellar Spectra.—As several of the photographic instruments had to be dismounted and adjusted specially for the total solar eclipse, it was necessary to considerably modify the programme of night observations. Photographs of five stellar spectra for the green region were taken with the 6-inch prismatic camera, using one prism of 45°; six stellar spectra were obtained with the 9-inch prismatic reflector before its removal, and the 2-inch quartz-calcite prismatic camera has been further employed in photographing thirteen pairs of stellar spectra, under conditions as nearly constant as possible, for recording extensions of the continuous spectrum in relation to the position of the stars on the temperature curve of chemical classification. With the 36-inch reflector an excellent photograph of the spectrum of the *Orion* nebula was obtained in January, with an exposure of $3\frac{1}{4}$ hours.

Total Solar Eclipse, 1905 *August* 30.—The eclipse was observed at Palma, Majorca. Special preparations were made to secure large-scale spectrograms of the solar chromosphere and corona, and two of the chief instruments were the prismatic camera of 6-inch aperture, having an objective by Henry and three large objective prisms of 45° angle, and a prismatic reflector having a concave mirror of 12-inch aperture and 72 feet focus, with an objective prism of 10-inch aperture and 11° angle. Three coronagraphs of varying aperture and a large-scale "three-colour" camera were also employed. Observations of shadow bands, colours of corona, landscape, &c., meteorology, and various other eclipse details were made. Unfortunately the weather conditions were very unfavourable, and only a small

number of photographs were obtained, even these being through thin cloud, including prismatic spectra of the corona and prominences, and several fairly good pictures of the corona. Excellent records of the shadow bands were obtained.

Publications.—Various papers dealing with celestial and terrestrial spectra comparisons, stellar temperatures, arc spectrum of scandium, variations of meteorological changes of barometric pressure and rainfall, and eclipse results have been communicated to the Royal Society. Numerous papers are in progress dealing with these and allied matters.

Stonyhurst College Observatory. (*Director, Rev. W. Sidgreaves.*)

The meteorological and magnetical continuous records have been in good working condition throughout the year, excepting only the vertical force balance, which has been dismounted and has not yet been replaced by a better construction.

The solar surface has been observed on all possible days, and drawings made of spots and faculæ. These number 196; and the surface has not been observed free from spots.

The Rowland grating has been employed on the larger Sun-spots by eye observation of the red end of the spectrum, and by photographs of the green and yellow regions. But the instrument was dismounted in the spring of the year, to make room for experiments with a smaller Rowland grating and a concave reflector, preparatory to use on the solar eclipse. And we are indebted to the Royal Irish Academy for the loan of an excellent cœlostat (by Sir Howard Grubb), through the kind recommendation of a lamented friend, the late Professor Joly. Experiments with this apparatus have also added to our collection of Sun-spot spectra.

The eclipse expedition to Vinaroz, undertaken by Fr. Cortie, secured some valuable photographs of the solar corona; but unfortunately the focus adjustment for the grating spectrograph for the "flash" was found to have had accidentally a wrong setting.

A larger cœlostat (15-inch mirror) has been kindly placed at our service by the Council of the R.A.S.; and experiments are being made for the mounting of this in conjunction with one of the 15-inch reflectors of the late Colonel Cross, in order to take part more efficiently in the international programme of observations of Sun-spot spectra.

The stellar spectrograph has been employed on every available night. But only 212 exposures have been made, owing partly to the unfavourable weather and partly to the present impossibility of utilising the early morning hours.

Wolsingham Observatory. (*Rev. T. E. Espin.*)

The work of measuring double stars has been continued during the past year. A catalogue of neglected double stars in the zone $+30°$ to $+40°$ has been prepared and numbers 663 objects. Of these 154 have now been measured on one or more nights, and the results, as far as they are completed, presented to the Society. During the year sixty-six new pairs were found.

Mr. Franklin-Adams's Astrographic Laboratory.

As there has hitherto been no report of the work at this Observatory a preliminary memorandum will be necessary.

When it was started some ten years ago, at Machrihanish House, Argyllshire, the scheme of work proposed was to take such photographs of the Milky Way as would be original and available as valuable material for information as to star-distribution; this scheme was, later on, extended to the charting of the whole heavens, north and south.

It was soon found that new lenses had to be designed. Whilst the first trial lens—6-inch aperture, F/4 focus—was being put through its preliminary tests in 1899, Professor Barnard, who was also seeking for a lens for a similar work, arrived in this country, came to the Observatory, and stayed for some time, making experiments and comparisons with a lens of his own; he and Mr. Franklin-Adams then paid two visits to Messrs. Cooke & Sons, of York, with the result that a new lens was ordered with slightly different figuring and focus. Professor Barnard, on his return to the States, entrusted to American makers the manufacture of his lens, while Mr. Franklin-Adams gave to Cooke & Sons an order for three lenses—4-inch, 6-inch, and 10-inch.

In 1902 an English equatorial mount was designed and made by Messrs. Cooke. A full report of this was communicated to the Society and published in *Monthly Notices*, vol. lxiv. p. 608, together with an account of a year's work with the complete instrument at the Cape in charting the Southern Hemisphere; this was completed at the Cape Observatory by the kind permission of Sir David Gill, who also gave much valuable assistance, including an electric installation and the taking of a series of plates in the astrographic telescope, corresponding to the centres of a defined number of plates in each zone of the Franklin-Adams chart. The photographic plates as finished were sent home in batches, and always in a steamer that did not carry their fellow transparencies, their numbers being as follows:

In. In.			Plates
15×15	chart plates—2^h exposure	... ...	127
12×10	"	"	127
15×15	"	three exposures of 7^m each... ...	127
Transparencies		... ...	381
		Total	762

The complete instrument and its house, weighing in all about twelve tons, were brought to England and erected at Mervel Hill, Hambledon, Surrey, in 1904, and were adjusted, and working well by the end of the year.

Report for 1905.

First—to carry on the report of the charting cameras during 1905—the transition from the brilliance of the South African skies to that of England was sad indeed. On very fine nights two hours twenty minutes is the exposure required to compare at all with the Cape work, but saddest of all is the frequent loss of time and cost of two plates, for with such large plates and the varying refraction, uncompleted plates cannot be carried on to the next fine night, but have to be sacrificed.

Subject to revision and final examination the following plates have been secured during 1905:

In. In.			Plates.
15 × 15	chart plates—usual exposure $2^h\ 20^m$	... ...	46
12 × 10	,, ,, ,,	... ...	46
15 × 15	,, triple exposure each of 7^m	... ...	38
	Total	... ...	130

As these have not to take the risk of crossing the sea it is not proposed to make transparencies.

Other instruments now mounted are:—Twin steel telescope carrying a 6-inch triple achromatic object-glass by Cooke, and an 8-inch by Wray (refigured by Mr. Dennis Taylor), both of 108-inch focus.

A 10° object-glass prism is mounted in such a way as to be available for either of the object-glasses. A new clock by Repsold has been bought and will replace the present controlled clock as soon as possible.

For time determination a meridian circle by Jones with object-glass of 3½-inch aperture and 57-inch focal length is used. Messrs. Cooke have added a new circle.

The Frodsham clock has been overhauled, cleaned, and furnished with a nickel-steel pendulum; it is mounted upon an isolated brick wall with two-thirds lime and one-third cement, and fastened with three 1-inch steel bolts. In a month after being mounted the clock gave very satisfactory results.

In the transit-room is a prime vertical by Troughton & Simms, object-glass aperture 3½ inches, focal length 42 inches.

All the buildings are lighted by a current of 120 volts and all the instruments by one of 15 volts. The English equatorial has electric motors in declination and R.A., the twin telescope in R.A. only; all instruments are in electrical communication with

the chronograph. It is driven by a slave clock in the transit-room, which itself is controlled by the Frodsham clock in the library.

The daily routine work consists of meteorological observations, including sunshine recorder and (weather permitting) time determinations, always accompanied by collimator, azimuth mark, and nadir observations.

Special work begun during the year consists of a series of Sun-spot pictures, taken with the twin telescope, upon very slow wet collodion plates, the slowness of which, together with the five-diameters magnification by a Barlow lens, gives an exposure which, compared to a rapid dry plate, is under one two-millionth of a second.

The other principal work done during the year was the organising of an eclipse expedition to Tunis, which came about in the following way :—

After the eclipse of 1900, when this Observatory took part with Dr. Copeland in the Scottish expedition to Santa Pola, Mr. Crookston, of Glasgow, who had a mining establishment in Algeria, bordering on Tunis, in the district of Boulhaf-le-Dyr, was asked to allow his manager to take meteorological observations for the summer and early autumn months; these were very satisfactory. When 1905 arrived Mr. Crookston offered to house the expedition. This offer would have been gratefully and at once accepted had it not been that Gijon, in the north of Spain, well known to Mr. Franklin-Adams in the eclipse of 1860, was unoccupied, because of its bad meteorological record, and it was nearly settled to go there. At this point Professor Becker, of Glasgow, who was proposing to go to Burgos, was asked whether the two Observatories could proceed together to Gijon, but after writing to the British Consul, and hearing about the class of steamers, it was finally decided to go to Tunisia, to a site about 3000 feet above sea-level.

The object of the expedition was (1) to secure automatic and exactly measured exposures of a long series of photographs for the determination of coronal intensity at various distances from the Sun's limb. This was carried out by Professor Becker with a most ingenious apparatus mounted and mostly constructed by himself. (2) To obtain photographs on slow wet collodion plates with the three short-focus Franklin-Adams lenses, 4 inches, 6 inches, and 10 inches, which would assist in investigation (1). On consideration, however, the last two were omitted, in order to avoid the stoppage of the charting work at home, and instead the 6-inch photo visual, focus 108 inches, was taken, together with a new mount by Cooke, specially made for an 18-inch mirror (borrowed from Edinburgh), and a new Repsold clock also specially bought, in order not to dismantle the English equatorial, and thus allow charting to go continuously forward. The result of the expedition when worked out will be published in due course.

All was entirely successful, excepting only the long-exposure photographs with the short-focus lens, which, on account of the strong light during the eclipse, were absolute failures, and would have been over-exposed in three seconds instead of the three minutes which were given.

A preliminary account of Professor Becker's work and instruments has been published by the Joint Eclipse Committee.

Mervel Hill is about 120 feet above the plain and 420 feet above sea-level; it slopes on the north side gently towards the Hog's Back, but has an abrupt descent to the south and west. From the house there is a splendid horizon, only interrupted as to a few degrees in two places; there is a prospect of over a thousand square miles. The site was chosen in preference to Crowborough or Hind Head on account of the much smaller number of nights obscured by the hill mists so prevalent upon sandy hills in the South of England.

The longitude has not yet been electrically determined; the six-inch Ordnance Map gives $2^m\ 30^s{\cdot}2$ W., $51^\circ\ 8'\ 11''$ N.

Sir William Huggins's Observatory, Upper Tulse Hill.

The photography of the spectra of stars and of other celestial bodies, which has been in progress for many years, is being continued.

Experimental work in the laboratory has included, in addition to the photography of spectra, further experiments in the radiation of radium, of which the results have appeared in the *Proceedings of the Royal Society.*

Rousdon Observatory, Lyme Regis, Devon.
(Sir W. Peek's; C. Grover, Observer in charge.)

The building and instruments have been maintained in their usual order, and observations were made on 132 nights. April was the most unfavourable month of the year; August to November were four remarkably fine observing months. The 6·4-inch Merz equatorial has been kept at the observations of long-period variable stars; 412 magnitude determinations have been made by Argelander's method. At each observation the light of the variable is estimated relatively to five comparison stars in the same field of view, the mean result being assumed to be the magnitude on the date of observation. During the twenty years this work has been in progress 9·300 magnitudes have been

recorded, and 361 maxima and 280 minima have been observed. About 25 long-period variables are under regular observation.

The lunar eclipse on February 19 and the solar eclipse on August 30 were well observed here.

Mr. Saunder's Observatory, Crowthorne, Berks.

Measures have been commenced on a photograph of the Moon taken by Mr. Ritchey with the Yerkes 40-inch refractor. Over 1800 points have been measured twice in one position of the plate. Three hundred of these have also been measured twice in the reversed position, and constants have been found for the plate. It has been found that it is now possible to use the method suggested by Professor Turner (*Monthly Notices*, vol. lx. pp. 202–205). This affords some indication of the progress made, as two previous attempts to use this method have failed in consequence of its not being possible to obtain a sufficient number of standard points whose positions were well known and widely distributed. The measures have been made, as before, by Mr. Hardcastle.

The telescope continues to be used chiefly for the study of fine detail on the Moon, and a map has been prepared for publication in the *Memoirs* of the B.A.A. showing the present state of our knowledge of the *Ptolemæus* region.

The telescope has also been occasionally employed for comet seeking.

Daramona Observatory, Streete, Westmeath. (*Dr. W. E. Wilson.*)

Practically no observing or photographic work was done during the past year. The long period of wet and cloudy weather from which we have suffered for some years seems to show little signs of passing away. During the past year rain was recorded on 246 days, although the amount measured was only $28''\cdot36$, against $36''\cdot27$ in 1904 and $45''\cdot72$ in 1903, when there were 265 wet days.

A quartz spectroscope was mounted for photographing the ultra-violet spectrum of sun-spots, but no work was done with it, as the Sun was seldom free from clouds. Experiments were made with a new apparatus for recording the amount of solar radiation.

Kodaikánal and Madras Observatories.
(*C. Michie Smith, Director.*)

The year was, on the whole, favourable for solar observations, and there were only twenty days on which no work was possible.

Photoheliograms were taken on 327 days, and the number and approximate positions of the spots and faculæ were determined by projection or by eye observations on 345 days. In all 294 new groups of spots were recorded during the year. There were two days on which no spot was visible (July 28, 29), and the mean daily number of groups was 4·7.

Spectroscopic Work.—Observations of spot spectra were made on 179 days, and prominences were recorded on 297 days. The spectroscopic observations have been made more completely than in former years, and a large number of interesting observations have been obtained. As practically all the work has to be done in the early forenoon hours and with a single instrument, the observations are still less complete than they ought to be, but as soon as additional assistance is available the eye observations will be supplemented by photographic work.

Spectroheliograph.—Photographs with the spectroheliograph were taken on 317 days. Over 1000 photographs were taken, but of these a considerable number had to be rejected for one reason or another. The instrument continued to give satisfaction except as regards the slits, which were a constant source of trouble. Steps are being taken to replace the collimating slit with one more suitable for the work that has to be done. Next to the slits the chief cause of trouble was the unsteadiness of the air. This, at times, is very serious. It is due largely to the unsuitable position chosen (during the director's absence) for the instrument. Various attempts are being made to get rid of this trouble, but the success, so far, is only partial. Many good spectroheliograms have, however, been obtained both of flocculi and prominences. The prominence plates are compared day by day with the records made with the spectroscope, and the published lists will in future contain all prominences observed both visually and photographically.

Publications.—Three *Bulletins* have been published containing observations of spot spectra and prominences, and a fourth dealing with spot spectra to the end of June 1905 is in type.

At the Madras Observatory astronomical work has, as for some years past, been confined to the observations necessary for the time service. The chief matter of interest during the year was the substitution of Indian standard time for Madras time from July 1. The new time is exactly $5^h\ 30^m$ fast of Greenwich mean time, and has been accepted over a great part of India. It is used over the whole of India for railway, postal, and telegraph purposes.

Melbourne Observatory. (Director, Mr. P. Baracchi.)

Meridian Work.—The following observations were made with the 8-inch transit circle :—

	Observations in R.A.	Observations in N.P.D.
Clock stars	541	—
Azimuth stars	299	104
List stars	1169	1173
Miscellaneous	3	3
Total	2012	1280

The list stars were, as in previous years, selected from the Melbourne Plates of the Astrophotographic Catalogue to be used as reference stars for the reductions of these plates. The total number of reference stars which have now been observed no less than three times in both R.A. and N.P.D. is 5211. These have been reduced as far as was required for the construction of the usual annual catalogues up to the year 1904 inclusive, and the places of about one-half of them have been brought up from the annual catalogues to the epoch 1900 as a commencement in the preparation of a general catalogue for that epoch, which will contain all the stars observed during the period 1894–1906, including the full list of reference stars required for the Melbourne plates at the rate of ten stars per plate.

Astrophotographic Work.—

	No. of Plates.		
	Passed as Satisfactory.	Rejected.	Total Number passed as Satisfactory up to 1905 Dec. 31.
Chart plates with triple exposures of 30^m each	74	3	556
Catalogue plates (second series) ...	25	2	316
Test plates on South Polar regions	20	—	—
Test plates on Oxford type charts	10	—	—
Plates for trails, adjustment of focus, centres, &c.	3	—	—

The measurement of Catalogue plates has been carried on, as in former years, by a special bureau. (See joint report for Sydney and Melbourne, p. 213.)

All the instruments which record photographically the variations of the magnetic elements, meteorological elements, and seismic disturbances have been at work throughout the year without interruption.

Further progress has been made in the measurement and reduction of the daily magnetic curves of all past years since 1868. It is expected that the register of hourly ordinates for the whole period up to 1905 December 31 will be completed this

year, after which the cataloguing and classification of disturbances for the same period will be taken in hand systematically.

The usual routine operations in connection with the following services have been carried on to meet local public requirements, as in previous years, viz. :—

The local and inter-State weather service,
The time service,
Registration of tides at four localities,
Rating of chronometers,
Testing instruments (surveying, meteorological, &c.),
The official verification and issue of standard weights and measures, &c. &c.

Sydney Observatory. (*Acting Director, Mr. H. A. Lenehan.*)

The transit circle has been in constant use, the chief work being observations of guiding stars for the astrographic plates.

Number of observations of	R.A. of stars ...	2395
„ „	N.P.D. of stars ...	2032

The Sun was observed on all available occasions. The cloudy weather, while lessening the number of meridian observations, gave an opportunity of bringing up the previous years' reduction to a more advanced stage. The 1904 constants have been computed and checked, stars identified, and precessions nearly finished. Progress has also been made with the 1905 reductions. The 11¼-inch equatorial was used for the eclipse of the Sun and for occultations, and visitors also were allowed to view the more interesting objects. There were 1405 visitors during the year, of whom 829 attended in the evening. Lectures with the equatorial or lantern slides occupied 78 nights.

The astrographic work at the Red Hill Branch was as follows: 193 plates were exposed, many being triple exposures of twenty minutes each. The stock of plates was examined and classified, and those showing any deterioration were noted to be re-taken. In conjunction with Mr. Baracchi, the Government Astronomer for Victoria, the reproduction of the charts has been discussed. The adoption of the French method of process prints, or the Greenwich method of reproduction on photographic paper, will depend upon the funds eventually placed at our disposal.

On February 20 a successful set of photographs of the lunar eclipse were taken, and Mr. Short also succeeded in obtaining a good series of photographs of the solar eclipse of March 6.

In the early part of January signals were received from the Washington Observatory *viâ* Vancouver, Fanning Island, Samoa, Norfolk Island, and Southport. Notwithstanding the five repeating stations the loss was only 2·96 seconds.

The Government Astronomer, Mr. H. C. Russell, retired on February 28. In view of the probability that the Observatory will be taken over by the Commonwealth Government no steps have been taken to appoint a new Director.

Joint Report of the Government Astronomers of New South Wales and Victoria on the Measurement of the Sydney and Melbourne Plates of the Astrophotographic Catalogue.

This work has been continued throughout the year by a special bureau established at the Melbourne Observatory and maintained at the joint expense of the Governments of New South Wales and Victoria, as stated on previous occasions.

The measurements were made with two micrometric machines constructed for the purpose by the Repsolds on the plan of Sir David Gill (as described in *Monthly Notices*, vol. lix. pp. 61–72), following the same methods and rules adopted in previous years.

Three new assistants were appointed during the year to fill vacancies caused by resignation or sickness.

The bureau is in full strength at present and the equipment is in good working order.

The measurements made during the year are as follows:—

99 Sydney plates, containing 74,797 stars.
79 Melbourne plates, containing 36,378 stars.

The whole work up to 1905 December 31 stands thus:

413 Sydney plates, containing 250,816 stars.
655 Melbourne plates, containing 223,645 stars.

Perth Observatory, Western Australia.
(Director, Mr. W. E. Cooke.)

Astrograph.—Progress is being made with the catalogue plates for the Astrographic Catalogue. Unfortunately a consignment of plates was lost by the wreck of the *Orizaba*, and work was delayed from February 11 till June 22.

During the year only 214 plates were passed as satisfactory, bringing the total up to 1088. It is difficult to know how to deal with these plates. It is impossible to measure them with the present staff whilst continuing the current programme, and it may be found necessary, as soon as the catalogue series is completed, to discontinue astronomical observations for some years, in order that the plates may be measured.

Transit Circle.—A change in the scheme of observations was made during the year, owing to the formulation of a new policy for the future. A notice of the new scheme has been already communicated to the Royal Astronomical Society, and the

following will probably be sufficient for the present sketch. The observing list comprises two or three stars in every square degree between the declination of 31° and 41° S. These stars were selected in the first place as standards for the astrographic plates, but it is now proposed to continue observing the same list over and over again, making, if possible, three determinations of position of each star per decade. At first the R.A. was made to depend upon the positions of equatorial stars in the *Nautical Almanac*, and the zenith distances upon nadir reflections. An entirely different method is now proposed. A list of 406 secondary standards has been prepared, each of which will be observed about ten times, and their positions in both co-ordinates will depend upon those of the stars in Dr. Auwers's Fundamental Catalogue situated between 31° and 41° S. These secondary standards will then be used to fix the positions of the stars in the main catalogue, which will be observed in zones of 2°.

The observation of the secondary standards was commenced on August 9, and 1842 observations have been made in both R.A. and Dec., and the reductions are well forward.

In the early part of the year, 1768 observations in both co-ordinates were made of the stars in the general list (zone 33°–34°). These were fully reduced and entered in ledgers. Zone 39°–40° was also entered in the ledgers, and a portion of zone 31°–32°. The following is the result of the year's work in tabular form :—

Nights on which time was determined ...	...	182
Observations of zone stars (33°–34°) in R.A....		1768
" " " " in N.P.D.		1768
Observations of secondary standards in R.A....		1842
" " " in N.P.D.		1842
Observations of clock stars in R.A. ...	...	954
Separate determinations of	Collimation error ...	13
	Level " ...	235
	Azimuth " ...	231
	Nadir point ...	58
	Flexure	4
Reading of meridian mark		112

Meteorological.—The usual meteorological work has been continued. A new system of issuing forecasts was started at the beginning of 1905, and has proved very successful.

Miscellaneous.—The time service has been efficiently maintained, but the time ball at Fremantle was dismounted at the beginning of May, owing to the erection of the fort, and remounted again on October 8.

Dr. Hessen arrived in Perth about the middle of October in

charge of the International Geodetic Observations for variation of latitude, and was able to mount his zenith telescope at the Observatory and make some preliminary observations. He has now established his Observatory at Bayswater, a suburb of Perth.

Dr. Alessio, navigating officer of the Italian cruiser *Calabria*, arrived at Fremantle in December, and made a determination of the force of gravity, and also the magnetic values at the Observatory. These will be eventually reduced and published by him.

Lovedale Observatory, South Africa. (Dr. Alex. W. Roberts.)

The work at Lovedale during 1905 has been on the same lines as in former years.

One hundred and five variable stars are under regular observation, and 4100 separate observations have been secured.

Especial attention has been directed to stars whose variation is apparently due to eclipse in some form. An attempt has been made to determine the orbital elements of the most remarkable of these stars, while towards the close of the year a scheme of observations was planned which might aid in the direction of arriving at some knowledge of the absolute dimensions of eclipse variable stars.

Mr. Tebbutt's Observatory, the Peninsula, Windsor, N.S. Wales.

The only astronomical observations made during the year 1905 are filar-micrometer comparisons during six nights of *Uranus* with the well-determined star I *Sagittarii*, and numerous measures of the interesting binary stars α and γ *Centauri*, Burnham 416, γ *Coronæ Australis*, and β *Muscæ*. All these observations have been made with the 8-inch equatorial, and will be communicated as soon as possible to the Society. The usual meteorological observations have also been made during the year.

Notes on some Points connected with the Progress of Astronomy during the Past Year.

Discovery of Minor Planets in 1905.

Fifty-eight new planets were discovered, or first announced, in 1905 as follows :—

Letter and Number.		Date of Discovery.			Discoverer.	Letter and Number.		Date of Discovery.			Discoverer.
PQ	...	1905	Jan.	1	Wolf	QX	...	1905	July	30	Wolf
PR	...	„	„	1	„	QZ	...	„	Sept.	4	Götz
PS	554	„	„	8	Götz	RB	...	„	„	19	„
PT	555	„	„	14	Wolf	RC	...	„	„	19	Wolf
PW	556	„	„	8	Gotz	RD	...	„	„	19	„
PY	557	„	„	14	Wolf	RE	...	„	„	19	„
PZ	...	„	Feb.	9	„	RF	...	„	„	22	„
QA	...	„	„	9	„	RG	...	1903	Sept.	22	Dugan
QB	558	„	„	9	„	RH	...	1905	Oct.	20	Wolf
QD	559	„	Mar.	8	„	RJ	...	„	„	20	Kopff
QE	...	„	„	13	Götz	RL	...	„	„	24	Wolf
QF	560	„	„	13	Wolf	RM	...	„	„	25	„
QG	561	„	„	26	„	RN	...	„	„	24	„
QH	562	„	Apr.	3	„	RO	...	„	„	25	„
QK	563	„	„	6	Götz	RP	...	„	„	25	„
QL	...	„	May	7	Wolf	RQ	...	„	„	26	Kopff
QM	564	„	„	9	Götz	RR	...	„	Nov.	3	Wolf
QN	565	„	„	9	Wolf	RS	...	„	Oct.	26	„
QO	566	„	„	28	Götz	RT	...	„	„	26	„
QP	567	„	„	28	„	RU	...	„	„	26	„
QQ	...	„	June	28	Wolf	RV	...	„	„	26	„
QS	568	„	July	27	Götz	RW	...	„	„	26	„
QT	569	„	Aug.	1	Palisa	RX	...	„	Nov.	1	„
QW	...	1904	Apr.	4	Frost	RY	...	„	„	1	„

Letter and Number.	Date of Discovery.			Discoverer.	Letter and Number.	Date of Discovery.			Discoverer.
RZ ...	1905	Nov.	1	Wolf	SE ...	1905	Dec.	17	Wolf
SA ...	"	"	3	"	SF ...	"	"	5	Metcalf
SB ...	"	"	3	"	SG ...	"	"	27	Wolf
SC ...	"	"	3	"	SH ...	"	"	24	Metcalf
SD ...	"	"	3	Kopff	SP ...	"	"	31	Palisa

569, SP, were discovered at Vienna, QW at Arequipa, SF, SH at Taunton, Mass. ; the remainder at Heidelberg.

The following planets do not receive permanent numbers, not having been sufficiently observed : PQ, PR, PZ, QA, QE, QL, QQ, QW.

The following identities have been established : PV with 149 *Medusa*, PX with 517, QC with 427, QE with 311 *Claudia*, QR with 216 *Cleopatra*, QU with 406, QV with 263 *Dresda*, QY with 167 *Urda*, RA with 429, RK with 509 *Jolanda*, 522 with KN, 550 with FT and also with LX, 566 with JF, 568 with an unnamed planet discovered 1891 December 1. The following identities are more or less probable : PU with 489 *Comacina*, QJ with 480, RN with 477 *Italia*, 526 with HA. Planet RJ is considered doubtful. A planet photographed on 1902 February 24, and at first supposed to be 462 *Eryphile*, proved to be 537 : this object was again photographed six days later.

522, 554 have been detected on plates taken 1901 August 23, 1900 September 30 respectively. In the latter case the planet was in the *Pleiades*, and being stationary it did not trail on the plate and so escaped detection at first.

The interesting planet 475 *Oello*, which has a very eccentric orbit, was re-observed last year, thus enabling its elements to be accurately determined.

The following planets have received names : 406 *Erna*, 485 *Genna*, 486 *Cremona*, 489 *Comacina*, 494 *Virtus*, 504 *Cora*, 505 *Cava*, 511 *Davida*, 520 *Francisca*, 522 *Helga*, 542 *Susanna*, 544 *Jetta*, 554 *Peraga*, 565 *Marbachia*, 566 *Stereoscopia*, 568 *Cheruskia*, 569 *Misa*.

Dr. Gustav Witt, the discoverer of 433 *Eros*, has reinvestigated the orbit of that planet from the observations of 1893, 1894, 1896, 1898, 1899, 1900, 1901, 1903. Those of the first three years are from Harvard photographs ; in 1903 only two observations are to hand, both made by Professor Millosevich in Rome. Perturbations by *Venus*, Earth, *Mars*, *Jupiter*, *Saturn* were computed at twenty-day intervals by Herr Wedemeyer. Sixteen normal places were found covering the ten years of observation, two different values being given to the 1896 normal according as some discordant observations were kept or rejected. In solving the normal equations an attempt was made to deduce a correction to the assumed mass of the Earth, and consequently to deduce a solar parallax. The values of the parallax deduced

are 8″·794 or 8″·803 according as one or other of the 1896 normals are employed; the observations of 1893, 1894, 1896 are evidently much less accurate than the later ones, as is only to be expected from the fact that the planet was still unknown and no special precautions could be taken to secure accuracy. There is every reason to hope that this gravitational method will in time give a very precise result for the solar parallax. The final elements are:

Epoch and osculation 1898 August 2·0, Berlin M.T.

	°	′	″	
M_0	205	4	51·8	
ϕ	12	52	24·2	
ω	177	39	11·2	1900·0
☊	303	31	48·2	1900·0
i	10	49	35·0	1900·0
μ	2015″·27547			

A. C. D. C.

New Satellites.

Two additional satellites of *Jupiter* have been discovered at the Lick Observatory by Mr. Perrine from photographs taken with the Crossley reflector. VI. was discovered in 1904 December, and VII. a month later; their magnitudes are 14 and 16, implying diameters of about 100 miles and 30 miles respectively. Their direction of orbital motion was uncertain for some time, but it has now been ascertained to be *direct* in each case; they therefore fail to support Professor W. H. Pickering's theory, described in last year's Report, according to which the motion of all very distant satellites should be *retrograde*. The interesting features are the high inclinations of the orbits to the primary's equator and orbit (in each case about 30°, though the two satellites move in quite different planes) and the near approach to equality in the sizes of the orbits. However, as the eccentricity of each is large and the major axes in different directions, the two orbits (which interlock like links in a chain) are about 1½ million miles apart at their nearest point.

Dr. F. E. Ross has computed the following orbits for these two satellites:—

Satellite. Epoch.	VI. 1905 Jan. 0·0 G.M.T.	VII. Same.
Mean Jovicentric R.A.	289°·1	328°·2
Longitude of Perijove	270	337
R.A. of N. Pole of orbit	86·7	191
Declination	84·5	64
Semi-axis major at dist. 5·2 ...	50′·6	52′·5
Period	251 days	265 days
Eccentricity	0·156	0·025
Motion	Direct	Direct

The elements of VI. were corrected by the observations of the satellite made in July, but those of VII. were only based on the two months following discovery, and while the position of the orbit plane is probably nearly correct, subsequent observations show that the period and eccentricity are erroneous; the former seems to be about 254 days, the latter about 0·20, the longitude of perijove about 132°.

Dr. Ross has also investigated the orbit of *Saturn's* ninth satellite *Phœbe*, which was again under observation in 1905. He has investigated and applied the solar perturbations, including the motion of the node and perisaturnium. The period and eccentricity are modified by these corrections, and become $550^{d}\cdot44$, 0·166. The annual tropical motions of π, ☊, i are $-0^{\circ}\cdot268$, $+0^{\circ}\cdot435$, $-0^{\circ}\cdot020$ (*Annals of Harvard College Observatory*, vol. liii. No. vi.).

Professor W. H. Pickering has announced the photographic discovery of a tenth satellite of *Saturn* with a period of 21 days, interesting from its large eccentricity and inclination and from the near approach which it appears to make to *Titan*. The orbit, however, cannot be considered as definitely known till further observations are available. A. C. D. C.

The Comets of 1905.

Few comets have been discovered during the year, but the following notes may be added concerning some mentioned in the last Annual Report.

Comet 1904 $a \doteq$ 1904 I. (parabolic) was followed at Strassburg till May 9, when the distance from the Earth was more than 5 R. The physical appearance and photometric changes of this comet have been discussed in great detail by Dr. C. W. Wirtz, of Strassburg, in *Ast. Nach.*, No. 4002.

Comet 1904 $d =$ 1904 II. was observed at Nice till May 2. Parabolic elements by Professor Aitken represent the path of the comet very accurately.

Comet 1904 $e =$ 1905 II. was last observed on May 24 at Washington. It is probable that the period of this comet will prove to be about seven years. Definitive elements have not yet appeared, and those of Dr. Wedemeyer founded on about four weeks' observations leave large residuals in the observed Right Ascension. It has been suggested that this comet may be identified with one that appeared in 1783, and for which the late Dr. C. H. F. Peters computed an ellipse of 5·89 years period.

Concerning the comets of the current year, 1905, on March 26 M. Giacobini discovered a telescopic comet as it was approaching perihelion. The comet became too faint for observation about the end of May, and the two months' observations are best represented by an ellipse of about 200 years period.

On November 17 M. Schaer, of Geneva, described a comet

which a few days later became visible to the naked eye. When first seen the comet was near the North Pole, but a rapidly southerly motion, coupled with loss of lustre, has prevented a long series of observations. There is no reason to suspect deviation from a parabolic path.

M. Giacobini added another to his list of cometary discoveries by detecting on December 6 a faint telescopic comet, the orbit of which is marked by small perihelion distance. As a consequence the comet can become very bright as it approaches the Sun. Observations are now discontinued, but the comet may become visible in daylight. After perihelion the comet should be seen in the Southern Hemisphere, and may be again visible in these latitudes later.

In addition to this list it is to be inferred from a telegraphic communication from the Lowell Observatory that Mr. Slipher obtained evidence of the existence of two comets on a plate exposed on November 29, one of which showed a double tail. As the announcement was not made for some time after the plate was taken, and the motion of the comets was uncertain, no further observations have been possible. The part of the sky photographed was in the constellation Aquarius.

Tempel's first comet (1867 II.), especially interesting on account of the unusual perturbation of its orbit, and for which a sweeping ephemeris was prepared by M. Gautier, passed through perihelion about April without being seen, though the conditions were favourable. Barnard's Comet of 1892 may also have passed its perihelion passage, but its position is very doubtful.

Definitive orbits of the following comets have been published during the year :—

Comet.	Character of Orbit.	Calculator.	Authority.
1886 VIII.	Parabolic	Fagerholm	*Ast. Nach.* No. 4047
1844 II.	Elliptic	Ross	*Ast. Nach. Ergänzungsheft*, No. 9
1903 III.	Parabolic	Peck	*Ast. Jour.* No. 573
1886 I.	Hyperbolic	Svedstrup	*Monograph*

The discussion of the orbit of the last-named comet by the late Dr. Svedstrup is particularly interesting. The comet was visible for several months, and forty-four normal places were formed, but these were not satisfactorily represented by the derived elements. Several hypotheses were tried with the view of effecting a better agreement, but the most satisfactory was to introduce into the equations of condition an additional term depending upon the mass of the comet. On solution a negative value for the mass was obtained, or the correction to the assumed mass of the Sun and comet combined was negative. This example, so far as it goes, shows that it is desirable to look for evidence of the action of radiation pressures in cometary obser-

vations. It also offers an independent proof of the generally received opinion that a comet is formed by the aggregation of a number of discrete particles. W. E. P.

Progress of Meteoric Astronomy in 1905.

January Meteors.—On January 2, during watches amounting in the aggregate to $2^h\ 11^m$ between $15^h\ 14^m$ and $18^h\ 44^m$, Mr. T. W. Backhouse, of Sunderland, saw 68 meteors, of which 62 belonged to the special shower of the epoch.

During the last five years fireballs have been very numerous in January, and the periods January 10–13, 24–25, and 27–29 appear to have been specially productive. The principal radiants have been in the region of *Monoceros* and *Hydra.*

April Meteors.—Moonlight and cloudy weather prevented observation.

August Meteors.—The shower was only a moderate one, and not very successfully observed. There occurred a fair number of fine nights during the first half of August, but at the time of the maximum display a gibbous Moon overpowered the fainter meteors.

October, November, and December Meteors.—None of these displays was well observed. Very few *Leonids* were expected, six years having elapsed since the probable (though unobserved) return of the parent comet in 1899, and the Moon was at the full. At Bristol on the morning of November 16 a few of the usual streak-leaving *Leonids* were seen from the normal radiant. On November 15 Mr. J. R. Henry, of Dublin, watched between $10^h\ 45^h$ and $14^h\ 35^m$ and counted 22 meteors, including 18 *Leonids.* The shower therefore returned in a distinct form, though its manifestation was by no means conspicuous.

The *Andromedids* of Biela's Comet were carefully looked for on November 18 and nights near that date, as there seemed a prospect of an abundant return. But the Earth encountered very few, if any, of these meteors. Reports from many widely distant places of observation agree that the shower was practically invisible. Mr. E. F. Sawyer, of Brighton, U.S.A., says that observations were obtained on every evening between November 14 and 30 (except November 15 and 28), and that meteors generally were scarce; those radiating from γ *Andromedæ* were remarkably so, only two small ones being recorded (on November 24) intersecting at $26° + 42\frac{1}{2}°$.

The absence of meteors from this rich system is noteworthy when we remember that it furnished showers in 1902, 1903, and (more conspicuously) 1904. Many of the meteors of the stream appear to have a shorter period and to be more widely distributed along the orbit than formerly. The dense group closely accompanying the comet seems to have experienced disturbance by *Jupiter* and *Saturn,* enabling it to pass more than a

million miles outside the Earth's orbit according to the computations of Dr. P. V. Neugebaur (*Proc. Royal Society*, A, vol. lxxvi. p. 270).

Though the *Andromedids* failed there were a few brilliant meteors from *Taurus* between November 19 and 24. These were seen by the writer at Bristol, Mr. C. L. Brook at Meltham, near Huddersfield, Rev. W. F. A. Ellison at Enniscorthy, and Mr. G. Smith at Bristol. The radiant of 9 well-observed paths was at $58° + 9°$. These slow long-pathed *Taurids* often present a well-marked display at the period of the *Leonids*.

The fireballs of the year were neither numerous nor well-observed. In January and February, however, large meteors were frequent (*Observatory*, vol. xxviii. p. 212), though succeeding months supplied few examples. At the close of the year (December 30) a magnificent object was seen in the early evening twilight (at $4^h\ 26^m$) by many observers in Scotland and the northern counties of England. It left a bright train, which assumed a zigzag shape and continued visible for a quarter of an hour. The observations are not very precise, but they indicate that the radiant was in the S.E. region of *Cetus*, and that the fireball descended from a height of about 60 to 47 miles during its long and slowly traversed path.

The following is a list of the real paths of a few bright meteors observed in England during the past year :—

Date.	G.M.T.	Brightness.	Height at First. Miles.	Height at End. Miles.	Length of Path. Miles.	Velocity per Sec.	Radiant Point.	Observers.
1905.	h m						° °	
Jan. 14	10 16	> ♀	60	29	55	15	119 + 3	3
27	11 58	½ ☽	66	33	53	7	118 ± 0	5
29	6 20	4 × ♀	57	25	67	23	130 + 33	5
Feb. 11	10 22	> ♀	51	32	46	13	150 − 7	4
11	10 31¾	= ♀	62	20	54	20	166 + 33	6
11	11 45	3 × ♀	63	46	40	12	145 − 13	13
28	12 10	> ☽	69	28	94	...	150 − 11	10
Mar. 18	8 47	½ ☽	47	43	60	...	168 − 23	2
May 10	12 45	> 1	69	39	43	32	137 + 76	2
19	9 50	♃	56	49	...	...	254 − 20	3
Aug. 9	10 17½	1½ ♀	69	52	32	...	44 + 59	2

Professor D. Eginitis gives a list of meteoric radiants recorded at the National Observatory at Athens in 1903 and 1904 in *Ast. Nach.* No. 4032. Dr. A. A. Nijland, of Utrecht, also summarises his observations of *Lyrids*, *Perseids*, and *Leonids* in the same number. Particulars of the *Andromedid* shower in 1904 November 21, as seen by Bohlin at Stockholm, are to be found in *Ast. Nach.* 3997.

Aerolite of 1902 *November* 15.—A recent number of the *Scientific American* gives details of the stony meteorite which fell with a great noise in Bath County, fifty miles east of Lexington, on the above date after a long luminous flight through the heavens above Ohio and Kentucky. Before striking the ground the mass divided into several fragments, three of which were found—viz. one of 184 lb., another of 10 lb. 10½ oz., and a third of ½ lb. "The large stone is furrowed and highly oriented. The trend of the furrows shows a regularity indicating the constancy in the position of its axis after the mass entered the air and in pursuing its lengthy flight. Its composition presents a base of fine compact olivine and enstatite with abundant sparkling points of nickel. It also has numerous white and grey spherical chondri of similar material distributed through it. Its surface exhibits a primary and secondary crust."

Aerolite of 1904 *August* 13.—Fell at 8 P.M. at Shelburne Grey County, Ontario, Canada. The noise accompanying its descent was heard over a radius of 35 miles. Two pieces were found distant from each other half a mile, the larger being 27¾ lb. and the smaller 13 lb. in weight. The stones fell vertically and could not have been hot, for the larger one, which buried itself 2 feet beneath the surface in a field of oats, carried with it a large burdock leaf which was green and uncharred. The velocity of the large stone was calculated at about 550 feet per second. That of the *Hvittis* meteorite was 590 feet per second. The meteorite which fell on 1881 March 14 at Middlesbrough, Yorks, appears to have exhibited a slower speed than either of these, for Professor Herschel calculated that its velocity on striking the ground was only 412 feet per second. It seems evident that when bodies of this character drop to the Earth, atmospheric resistance and terrestrial attraction have robbed them of their original speed and direction, and that their motion is extraordinarily slow in comparison with the planetary velocity exhibited by ordinary shooting stars at normal heights in the air.

W. F. D.

Total Solar Eclipses.

1905 *August* 30.

As pointed out in last year's Report this eclipse derived considerable importance firstly from the fact that it was the last one visible from any accessible place for many years, and secondly from the long interval of time that elapsed between totality in Labrador and in Egypt. Extensive arrangements were accordingly made for its observation.

A large number of French observers were distributed along the line in Spain, Algeria, and Tunisia, among whom we may note:—

MM. Janssen, Millochau, and Stefanik at Alcosebre; M.

Deslandres at Burgos; MM. Trépied, Salet, Bourget, Montangerand, and many others at Guelma or its vicinity; M. Bigourdan at Sfax.

The preliminary reports of most of these parties have been published in *Comptes Rendus* (1905, No. 12 *et seq.*), from which we may extract the following points of interest:—

M. Trépied obtained photographs of the corona and chromosphere confirming the close connection between the forms of the coronal streamers and regions of solar disturbance, and one showing the whole of the Moon's disc outside totality. His photographs also show the elliptical rings in the corona which are such a marked feature of the large-scale plates taken by the Astronomer Royal at the same station.

M. Deslandres was unfortunate in his weather, as the Sun was covered with clouds at both second and third contacts. A partial clearance, extending over about one minute during the total phase, enabled some measurements of the brightness and total luminosity to be made, the reductions of which have not yet been published.

M. Salet at Robertville, in Algeria, made some polarimeter observations with a "Savart," and found bands showing radial polarisation up to a distance of $1\frac{1}{2}$ solar diameter from the limb. The maximum polarisation was found at $5'$ or $6'$ from the limb, and it was noted that the presence of prominences had no apparent effect upon the bands, thus putting "out of doubt the non-polarisation of protuberances."

MM. Bourget and Montangerand at Guelma obtained good spectrum observations, though their spectra of the corona show only the "green" line. A discussion of their prismatic camera photographs leads them to the conclusion that there is marked division of the chromosphere into two regions or shells—viz. the lower or "reversing" layer, extending only $1''$ from the limb, and the upper or "chromospheric" layer, extending to $3''$ or $4''$.

Measurements of the intensity of the continuous coronal spectrum showed that, as compared with that of diffused sunlight, it was more intense in the region from λ 4700 to λ 6000, the difference being greatest at λ 5500. In other words, as analysed in the spectroscope, the coronal light contains less blue and violet but more green and yellow than sunlight—an important point to bear in mind in discussions upon the polarisation of the corona and the question as to what proportion of its luminosity is due to light reflected from small particles.

M. Fabry made some careful and valuable measurements of the total and intrinsic light of the corona. For the former purpose he employed a Lummer photometer with a cell filled with an ammoniacal solution of sulphate of copper interposed between the standard light and the screen to harmonise the tints. His value for the total luminosity was 0·13 candle at one metre, which equals about three-quarters of the light of the full Moon, a result closely accordant with other recent determinations.

Some of the earlier observations gave very high values, ranging up to 25 full Moons, and must now be set aside. M. Fabry is of opinion that all the other values of any weight lie between 0·1 and 0·2 candle, while the full Moon is 0·175. He thus concludes that the average total intensity of the corona is not very different from, though probably slightly less than, that of the full Moon.

As regards the intrinsic illumination he found that the brightness at 5′ from the limb in the direction of the equator was equivalent to 720 candles per square metre as compared with 2600 candles for the full Moon, a ratio of 0·28 to 1, a value closely confirmatory of Professor Turner's ratio of 0·25 to 1.

The parties from the Lick Observatory were stationed at the two extreme ends of the line in Labrador and at Aswan. No observations were obtained at the western station, so that their hope of getting any photographic evidence of a change in shape of the corona during an interval of 2½ hours was not realised. Mr. Maunder was also in Labrador and was equally unfortunate.

Professors Campbell and Perrine were at Alhama, in Spain, where the weather was also cloudy.

Professor Todd was at Tripoli with a battery of cameras, the largest of which was provided with a lens of 12 inches aperture and was fitted with orthochromatic screen and a Burckhalter occulter. A number of photographs were secured.

The preliminary reports of the British parties have already been published (*Proc. R.S.* A No. 514) and we may here briefly summarise some of the more important results.

The weather conditions prevented either of the parties stationed in Spain—Mr. Evershed, at Pineda de la Sierra, or Professors Callendar and Fowler, at Castellon de la Plana—from obtaining any observations.

Sir N. Lockyer's party at Palma, Majorca, got only a partial view of the phenomenon through a break in the clouds towards the end of totality enabling some exposures to be made with the prismatic cameras and coronagraphs.

On the other hand Mr. Newall, at Guelma, was favoured by particularly good atmospheric conditions, and was able to carry out an extensive programme. A repetition of his previous attempt to determine the rotation of the corona by photographs of the "green" line with a double-slit spectroscope met with no better success than on the previous occasions, the light of the corona at 3′ from the limb failing to impress the photographic plate. His arrangements for attacking the problem of the polarisation of the coronal light were very complete, and comprised a "Savart" camera of 1·5 inch aperture, a "Nicol" camera of 2 inches aperture, and a polarising spectrograph. He also used an objective grating camera and two simple cameras.

The polarimeter observations will, when completely reduced, give quantitative values of the coronal polarisation, and they

show that the atmospheric polarisation was nearly horizontal and was about equal to the radial polarisation of the corona at $1\frac{1}{2}$ diameter from the limb.

The Astronomer Royal and Mr. Dyson were at Sfax, in Tunisia, equipped with the Thompson photographic telescope, giving an image on a scale of 4 inches to the Moon's diameter, another camera with the object glass of the astrographic equatorial, giving an image on a scale of $1\frac{1}{4}$ inch to the Moon's diameter, two small-scale cameras and two slit spectroscopes, used before in 1898, 1900, and 1901.

The photographs obtained with the Thompson coronagraph show interesting detail in the inner corona, especially remarkable being the oval rings, already alluded to, and the arched structures above the prominences. Mr. Dyson's photographs of the coronal spectrum show two new lines at λ 5536 and λ 5117.

Professor Turner, with Mr. F. A. Bellamy, was at Aswan, Egypt, where, with the exception of a slight haze due to dust, the state of the atmosphere was entirely favourable. He was accompanied by Mr. J. H. Reynolds, who was provided with a mirror of 2 feet aperture and 120 feet focal length, fed with light from a cœlostat of 28 inches diameter. The plates obtained with this instrument were unfortunately spoiled, owing to the grain of the wooden slides having impressed its image upon the film.

Professor Turner's observations were directed to the determination of the photographic intensity of the coronal light at varying distances from the limb and the quantitative measurement of the fraction of this light found to be radially polarised. A good set of plates was obtained, the complete measurement and reduction of which will be a matter of considerable labour.

In addition to the official British parties Professor L. Becker and Mr. Franklin-Adams were at Kalaa-es-Senam, Tunis, the former of whom made a series of exposures upon the corona for photometric purposes, the exposing apparatus being accurately controlled by a pendulum clock, while the latter secured some excellent direct views of the corona. Father Cortie also obtained successful photographs in Spain.

Besides the observers already mentioned there were many others, of whose work no detailed reports are yet to hand. Among these we may mention Professor Riccò and Mr. Rotch ; parties from the U.S. Naval Observatory in Spain ; parties of Russian astronomers in Spain and at Aswan, of German astronomers in Algeria and Spain ; members of the British Astronomical Association at Burgos, and many others.

It is stated that there were altogether no less than eighty observing stations occupied, so that, in spite of partial failure due to clouds, there is still a large bulk of observations to be reduced and discussed.

Any general deductions as to the lessons of the eclipse must be deferred until we are in possession of more complete details.

E. H. H.

Solar Activity in 1905.

Sun-spots.—The Sun-spot record for 1905 showed a very remarkable contrast to that of the previous year. Very early in January a scattered stream of rather small faint spots was seen upon the Sun, which passed off at the west limb in the usual course without having displayed any feature at all remarkable. The group returned, however, in the next rotation under a very different guise. It was now one immense spot of complex structure, the largest single spot as yet photographed at Greenwich. This was the first of a succession of great Sun-spots easily visible to the naked eye. The group returned for the third time to the visible hemisphere on February 25. It was still very large, though greatly shorn of its former proportions. Four days later another great spot was seen; and in May, June, July, and August, and again in October and November, enormous groups have appeared on the Sun. During the earlier part of the year the solar activity, considered apart from these great groups, did not appear to be increasing very fast; but towards its end, and especially in the month of November, the groups of spots were very numerous as well as large, and formed two great belts across the Sun. The mean daily total area will probably work out as about double that for 1904, so that the tide of increase is in full flood. The increase in faculæ has also been very marked.

The mean latitude of the spotted area was about 14° or 15° from the equator—that is to say, the zone usually occupied at maximum has already been reached. E. W. M.

The Prominences.—The mean daily number of prominences, from observations made on 95 days during 1905, is slightly less than the previous year's record. This reduction of activity is confined to the southern hemisphere, which shows a very marked falling off, whilst the northern hemisphere has increased a little The figures obtained are as follows:—

	1904.	1905.
North hemisphere	4·92	5·20
South "	5·14	4·15
Total mean numbers per diem ...	10·06	9·35

The polar regions of the Sun have again been nearly quiescent, although the high latitude zones of activity have made a distinct advance towards the poles. These prominences were found to be most frequent between the parallels 65° and 70° in both hemispheres, and the limits of prominence-formation at the close of the year may be put at +75° and −75°.

The northern hemisphere has been especially active in metallic prominences, nearly 5 per cent. of the total number of northern prominences strongly reversing the sodium and magnesium lines; 3 per cent. only of the southern prominences were

metallic. This type of prominence has been entirely confined to the zones $+9°$ to $+35°$ and $-9°$ to $-35°$.

A remarkable eruption was observed on January 29, apparently directed from the centre of the great spot group then near to the east limb. This outburst was characterised by an entire absence of metallic reversals. Strongly metallic eruptions were, however, subsequently witnessed in the same spot region, notably one on February 2, recorded by Fowler in *Monthly Notices*, lxv. 513. In this case, as in a similar eruption seen by the writer on November 10, 9^h 15^m to 9^h 35^m A.M., the sodium, magnesium, and enhanced iron lines were brilliantly reversed for a short time on the bright background of the Sun's disc. It may be remarked that the magnetograph records of Greenwich and Stonyhurst Observatories show very minute disturbances on February 2 and on November 10 exactly synchronising with the active phases of the two eruptions. J. E.

Double Stars.

The same classification is adopted as in previous reports. The abbreviations are :—

M. N.: Monthly Notices R.A.S.
A. J.: Astronomical Journal.
L. O. B.: Lick Observatory Bulletin.
A. N.: Astronomische Nachrichten.

Observations—

L. O. B., No. 74. *W. J. Hussey*
L. O. B., No. 77. „
L. O. B., No. 81. „
Four hundred new double stars found whilst at the Lick Observatory. These catalogues bring Professor Hussey's double stars up to 1200.

M. N., lxv. 7. *Rev. T. E. Espin.* A catalogue of seventy new double stars.

M. N., lxvi. 3. *Rev. T. E. Espin.* A catalogue of 51 new double stars and measures of 120 known pairs.

M. N., lxvi. 1. *Royal Observatory, Greenwich.* Measures of 433 double stars made in the year 1904 with the 28 inch refractor.

A. N., No. 4022. *J. A. Miller and W. A. Cogshall.* Measures of 102 stars found by the Leipzig observers in zone $+10°$ to $+15°$.

A. N., No. 4054. *H. F. Lau.* Measures of 82 pairs with a 6-inch refractor at Copenhagen.

A. N., No. 4056. *P. Sternberg.* Photographs of double stars taken at Moscow :—

		°	′
Castor	1904·16	223·8	5·55
ξ Ursæ Maj. ...	1904·23	139·4	2·64
γ Virginis ...	1902·36	328·4	5·82
"	1903·28	328·3	5·82
"	1904·30	327·9	5·86

A. S. P., No. 101. *R. G. Aitken.* Measures of *β* 208 and *β* 524.

A. S. P., No. 102. *R. G. Aitken.* Measures of Σ 2481 BC and new companions to Σ 419, Σ 1000, Σ 1823.

Publications of the University of Pennsylvania, vol. ii. part 3. *E. Doolittle.* Measures of 1066 double and multiple stars made at the Flower Observatory with the 18-inch refractor during the years 1899 and 1905. A fine set of measures in continuation of those already published in vol. i.

Popular Astronomy, 1905 *February. W. W. Campbell. Castor* as a quadruple star—*i.e.* each visual component is a spectroscopic binary.

A. N., No. 4067. *H. Ludendorff.* On a remarkable change in the spectrum of *ζ Boötis.*

A. S. P., No. 101. *W. W. Campbell.* Variable velocity of *Sirius* in the line of sight.

Calculations—

L. O. B., No. 71. *R. G. Aitken.* Orbit of *β* 395, period 24·0 years.

L. O. B., No. 80. *R. G. Aitken. ξ Scorpii.* Observations during the years 1900–1904 lead to a period of 44·5 years—*i.e.* half the previously adopted period.

L. O. B., No. 84. *R. G. Aitken.* A catalogue of orbits of binary stars, distinguishing between the reliable and non-reliable orbits.

L. O. B., No. 71. *R. G. Aitken.* Note on 13 *Ceti* (Hough 212).

A. N., No. 4051. *W. Doberck.* Orbit of *σ Coronæ Bor.*, period 1679·2 years.

A. N., No. 3989. *W. Doberck.* Orbits of Σ 186, Σ 1785, Σ 1879, Σ 1888, Σ 2026, and OΣ 285.

A. N., No. 4063. *W. Doberck.* Orbits of *τ Ophiuchi* and *γ Centauri.*

A. N., No. 4064. *N. E. Nörland.* Orbit of *ξ Ursæ Majoris*, period 59·8 years.

Untersuchungen über das Doppelsternsystem 61 *Cygni*— 1905 *Upsala. Osten Bergstrand.* A determination of the parallax

from his own photographic plates, and a general discussion of proper motion and relative motion. He clearly shows the connection of the two stars and deduces a final parallax $+0''\cdot 2926 \pm 0''\cdot 0073$. T. L.

Variable Stars.

Large additions to the list of variable stars continue to be a feature of astronomical work during the past year. For example, the official numbers assigned to variables for 1904 run up to at least 283, and in 1905 up to 106; while Professor E. C. Pickering announces (apparently in addition to the foregoing) 843 new variables in the smaller Magellanic cloud (*Harvard Circular*, No. 96). It seems certain that only a proportion of the known variables can now be followed up by observation through their changes, and hence, next to discovery, the close study of some particular class of variation or some particular star is often taken up.

Among such discussions we may refer to that of Dr. Meyermann, who considers that the variation of δ *Cephei* can have nothing to do with the obscuration by a satellite, but attributes the variation in light to a change of radiation in the two bodies forming the "star" consequent on their varying distance from one another (*Ast. Nach.* 3985).

Mr. J. H. Jeans, discussing Algol-type stars, thinks that gravitational instability has not hitherto been taken account of in calculating the density, and considers that nothing is known but the period of rotation; nothing can be inferred as to the structure or nature of the system (*Astrophysical Journal*, xxii. 2).

Mr. T. W. Backhouse has published a volume of his own observations of nearly fifty variables, made in the years 1866–1904.

An apparently new star in *Pegasus* (159, 1904) was discovered by Mr. Stanley Williams. This has been found from the Harvard photographs to have existed for some years and to be a variable star (*Ast. Nach.* 3973).

48 *Aurigæ*, discovered to be variable by Mr. T. H. Astbury, a member of the British Astronomical Association, is interesting on account of its brightness. It can be easily followed in a binocular. Variation, $5^{m}\cdot 0$ to $5^{m}\cdot 6$. Period, probably about 3·8 days.

Another interesting discovery is that of the Algol-type variable *W.* 2 *Tauri*, made at Harvard College Observatory from photographs. The variation is unusually large, viz. from $7^{m}\cdot 14$ to 11^{m}; period, 2·77 days. The amount of variation is greater than that of any other Algol-type star known (*Harvard Circular*, No. 104). E. E. M.

New Reduction of Groombridge's Catalogue.

An extraordinary amount of energy has been devoted for some years to the first reduction, re-reduction, revision, or re-observation of old collections of star places.

The following have already been published: the re-reduction of Bradley, Mayer, and Pond (1811–19); the revision of Taylor; the reduction of Bessel's observations with Dollond's transit and the circle of Cary; the Paris Catalogue, containing the meridian observations from 1837–81; several Cape Catalogues of an early epoch; the revision of Lamont's *Zones*; Bossert's *Supplément à l'Histoire Céleste*; Auwers's *Fourteen Unknown Zones of Bessel*; Weiss's new edition of Argelander's *Southern Zones*; the re-observation of Piazzi.

An early publication of the following may be expected: the re-reduction of Piazzi's own observations; of those of Henderson in Edinburgh; of Plantamour in Geneva; of Rümker's, Lalande's, and the Washington zones; a revised edition of Argelander's *Northern Zones*; the re-observation of Schjellerup's stars; and probably a few others.

At the same time the *Geschichte des Fixsternhimmels*, started in Germany, and which inspired or stimulated several of the above-mentioned works, has begun to make an exhaustive collection of all the accurate meridian observations made between 1750 and 1900. This work, when finished, will give all the data relating to any one of the stars in the most complete and convenient form.

The effect of this vast amount of work will be (the words were applied by Auwers to the last-mentioned work exclusively) "to ensure to sidereal astronomy the permanent possession of all the riches gained by the combined efforts of the observers and computers engaged in meridional work during the 150 years which sever the beginning of the twentieth century from the beginning of meridian work of precision."

The importance of the older collections of observations evidently lies in their value for the derivation of proper motion. Those derived from a comparison of Bradley's observations with modern catalogues have been in the past the main material in the treatment of sidereal problems; but Bradley's telescopes had apertures of only about 1½ inch, and hardly any star in his catalogue is fainter than 7th magnitude. The consequence is that for the fainter stars, between magnitudes 7 and 9, we have mainly to rely on comparisons of the older zone observations of Lalande, Bessel, Lamont, &c., with the Catalogue of the Astronomische Gesellschaft. Precious as the data are which these comparisons furnish, they cannot in any way compare with the proper motions of the Bradley stars.

To see how inadequate they are to the demands of investigators in sidereal astronomy it is sufficient to consider that it is

hardly possible to derive from this material, in a satisfactory way, either the average proper motion of the stars between $7^{m}\cdot 0$ and $9^{m}\cdot 0$, or the percentage of proper motions above or below the average. On the other hand, the time is rapidly approaching when photography will furnish numerous accurate proper motions of stars fainter than the 9th magnitude. Any source yielding numerous accurate proper motions of stars between magnitudes 7 and 9 must therefore be doubly welcome.

Among these the catalogues of Piazzi and Groombridge stand foremost, and their re-reduction and re-observation have been a long-recognised *desideratum*. The latter work has now been completed. The observations of Groombridge (1806–1816) have been re-reduced wholly *de novo*, with the exception only of the conversion of the original readings of the microscopes, which seem to be lost, into readings of zenith distance.

The main difficulty in the way of a fundamental reduction of the right ascensions arose from the fact that "most of the stars within 10° of the Pole were observed within the first two years, and, generally speaking, it seemed as though Groombridge from time to time made lists of say a hundred stars or so, which, as soon as he had obtained some five observations, he struck off and never re-observed."

The consequence has been that practically only the observations of right ascension made in 1807 could be reduced fundamentally. For this period standard positions of *Polaris* were derived from consecutive upper and lower transits, and of other stars from Groombridge's observations on nights on which *Polaris* was also observed. Where these were still found "insufficient to give azimuth errors for every day's observation, supplementary lists of stars whose places depend on observations on days on which some of the standard polars were also observed were drawn up, and these stars, where necessary, have been used for the determination of azimuth error."

For the other years this "attempt to make Groombridge's right ascensions practically fundamental could not be sustained," and the azimuth error had, to a great extent, to be derived from the positions of stars contained in Newcomb's Fundamental Catalogue. No appreciable systematic error appears to have been introduced by this difference in treatment.

Even for a differential reduction there remained great difficulties. In regard to the right ascensions the main difficulty consisted in the want of materials for separating the collimation error from the azimuth error, so that the correction formula $m + n \tan \delta$ had to be used instead of $m + n \tan \delta + c \sec \delta$. In regard to the North Polar distances, which were all reduced strictly differentially by using all the Newcomb stars observed on each night for the derivation of the polar points, the chief difficulty lay in the determination of division errors.

The effect of the first difficulty has been greatly reduced "by the small limits of N.P.D. within which Groombridge usually

chose his stars for a night's observation," and by taking "all stars between 35°–52° N.P.D. for which reliable places could be found as adjuncts to the clock-error."

The determination of the division errors was successfully made by a comparison with the positions in Newcomb's Fundamental Catalogue. As the instrument was reversible and there were two circles, the two positions of the independent corrections for the same distances from the zenith were between 25° and 52°. For N.P.D. 10° to 25° a single determination was obtained, whereas the division errors for the few stars within 10° of the Pole had to be neglected for want of sufficient materials for their determination.

That both the difficulties for the right ascensions and the declinations have been overcome with a considerable degree of success appears best, perhaps, in the former case by the agreement of the values Groombridge-Newcomb for the faces east and west; in the latter by the agreement of those division errors for which two independent determinations were obtained.

Proper motions have been derived for every star by combining Groombridge's observations with modern Greenwich Catalogues, mainly with the Second Ten-Year Catalogue, Epoch 1890, giving an average difference of epoch of about eighty years.

These proper motions, the accuracy of which would seem to be of the order of those of Auwers-Bradley, constitute the main result of the whole work.

The intermediate positions of Radcliffe 1845 and the Catalogues of the Astronomische Gesellschaft have been compared, but have only served in the derivation of proper motion in very exceptional cases.

The authors have availed themselves of these new materials to get a new determination of the constant of precession and of the elements of the solar motion in space. They are led to a somewhat unexpectedly large correction of Newcomb's precession—viz. an increase of $\frac{1}{10000}$th part of the whole. They further derive a series of values for the positions of the apex for stars of different spectrum, different amount of proper motion, and different magnitude, which finally are united in the concluded position

$$A = 275^\circ \qquad D = +37^\circ.$$

The main advantage of these determinations lies in the fact that the motions on which they rest consist largely of new material. On the other hand, they labour under the drawbacks that this material "is confined to a very limited region of the sky" and that "the large relative preponderance of stars of large proper motion about 12^h of right ascension" . . . [which brings clearly out the well-known fact that the apparent motions of the stars in high galactic latitudes are greater on an average than those of stars in or near the Milky Way] "may well affect the determination of the position of the apex."

The Introduction further shows the distribution of the proper motions according to magnitude, amount of proper motion, and spectrum, in an extremely clear, concise, and complete way, which will command the gratitude of any investigator of stellar motions; and the Catalogue, by the number of accurate proper motions of small stars which it contains and the care bestowed on its reduction, may safely be considered as the most valuable contribution of material for the study of sidereal motions since the publication of the third volume of Auwers-Bradley.

The Greenwich Observatory, and in particular Messrs. Dyson and Thackeray, are cordially to be congratulated on the successful conclusion of this great work. J. C. KAPTEYN.

Second Meeting of the International Union for Co-operation in Solar Research.

At the first meeting, held at St. Louis on 1904 September 23 (of which a brief account is given in the last Council report), Oxford and Meudon were suggested as places for the next meeting. The Executive Committee accepted the invitation to meet in Oxford, which was accompanied by a hospitable offer on the part of the Warden and Fellows of New College to entertain the foreign delegates.

The Executive Committee met to arrange a provisional programme on Monday, September 25, and the Union sat for scientific discussions on the mornings of September 27, 28, and 29; and for discussion of the proposed constitution on the afternoon of September 27. Among the chief decisions arrived at were the following:—

(*a*) A definite procedure was settled for the adoption of standard wave-lengths. The wave-length of a suitable spectroscopic line is to be fixed permanently, thereby defining the unit of wave-length. A committee was appointed to select secondary and tertiary standards.

(*b*) A standard instrument (Ångström's pyrheliometer) was adopted for the measurement of solar radiation, and a committee was appointed to draw up a scheme for promoting co-operation.

(*c*) General principles were laid down for guidance in schemes of co-operation in different branches of solar work; and it was determined to select in the first instance the two following branches of research for special attention by the Union:—

(1) The study of the spectra of sun-spots.
(2) The study of the records, by means of the H and K light, of phenomena of the solar atmosphere.

Twenty-five actual delegates, and a dozen or more interested visitors, were present at the meeting. The next meeting was fixed for about September 1907 at Meudon, the actual date to be

decided by the Executive Committee (Professors Schuster and Hale, with a third member to be appointed by the International Association of Academies). H. H. T.

The Astrographic Catalogue and Chart.

In last year's report it was stated that the weak link in the chain was the zone from 17° to 40° south declination, which appeared to be making slow progress. This, happily, seems in a fair way of being remedied, in part at least, for the Santiago Observatory, to which the zone 17° S. to 23° S. was originally allotted, but which had been seriously hampered in its work, first by the death of its director, Professor Maturana, and then by want of money owing to political troubles, is now in more satisfactory circumstances; and by direction of M. Obrecht, the present director, his chief assistant, M. Ernesto Greve, has visited European observatories during the past year to learn details of the work preparatory to beginning the zone. There is no specific information from M. Thome at Cordoba, who is undertaking the next zone southward—*i.e.* from 24° to 31°—but the state of the work in the zones between this and the South Pole can be learned from the reports of the Observatories at Perth, the Cape of Good Hope, Sydney, and Melbourne, who share this area. M. Valle, of Tacubaya, has lately reported that for the zone for which he is responsible—10° S. to 16° S.—1000 Catalogue plates have been taken, and that a zone of declination one degree broad is nearly reduced.

The work on the zones of the northern hemisphere of the sky is proceeding on the lines given in former reports. The second volume of the rectangular co-ordinates of stars measured at Greenwich is being printed, and more than two-thirds of this is in type, which completes about five-sixths of the Greenwich zone. Funds have been supplied for printing the Oxford measures, and this work is in hand. The only publication during the year was the first volume of the zone undertaken by the Bordeaux Observatory, which gives the rectangular co-ordinates of the stars measured on the plates whose centres are at declination 17° N., exactly in the form adopted by the other French observatories. The introduction to this volume contains discussions by M. Rayet, the director, on various points, such as the accidental error of measurement due to the shape of the images and on other sources of error to which results are liable. There is also a memoir by M. Kromm on the *rattachement* of plates, illustrated by measures of a series of plates covering the *Pleiades* area, with a catalogue of the places of 196 stars of the group deduced from photographs.

The enlargement of the Chart plates before described is being continued. The number of reproductions now distributed

to date (February 1) is:—Paris, 222; Algiers, 207; Toulouse, 107; San Fernando, 46; Bordeaux, 40; Rome, 3; Greenwich, 322.

H. P. H.

Stellar Spectroscopy in 1905.

Nebulæ.—Dr. J. Hartmann's monochromatic photographs of the *Orion* nebula (*Astroph. Jour.* xxi. 389) show that the light which is effective in giving photographic portraits of such a nebula is very different in different parts of the nebula. The extraordinary intensity of the light of wave-length λ 3727—the existence of which was first proved in 1881 by Sir William Huggins—again draws attention to the need for the discovery of the origin of this light. Dr. Hartmann's observations point to the presence of at least three gases which contribute luminosity to the nebula.

New Stars.—Professor E. C. Pickering gives reasons (*Harvard Circular*, No. 99; *Astroph. Jour.* xxii. 90) for regarding *RS Ophiuchi* as a Nova rather than as a long-period variable star. "Its proper designation will be Nova *Ophiuchi*, No. 3, the new stars of 1604 and 1848 having also appeared in the same constellation."

Nova *Aquilæ*, No. 2. Professor Pickering announces (*Harvard Circular*, No. 106; *Astroph. Jour.* xxii. 271) the discovery by Mrs. Fleming of a second Nova in *Aquila*, and gives a brief description of its spectrum.

Messrs. Moore and Albrecht give a short note on the spectrum of Nova *Aquilæ*, No. 2 (*Pub. Astr. Soc. Pac.* xvii. 156).

Professor W. H. Julius discusses (*Astroph. Jour.* xxi. 286), from the point of view of anomalous dispersion, the bands in the spectrum of Nova *Persei*.

A portfolio of photographs of the spectrum of Nova *Persei* by the late Frank McClean has been published by Stanford, London. It contains six plates of enlarged spectra, and also reprints of Mr. McClean's notes published in the *Monthly Notices*, together with a short note by Mr. Newall on the later photographs.

Classification of Stellar Spectra.—Sir Norman Lockyer contributes (*Proc. R. S.* vol. lxxvi. 145) further experimental evidence about the relative distributions of energy in the spectra of different stars. The difficulty of reasoning upon data of this kind is well exemplified by the conclusions with which the note ends.

Dr. W. E. Wilson (*Proc. R. S.* vol. lxxvi. 374) gives general considerations on the evolution of the spectrum of a star during its growth from a nebula, and these lead him to the conclusion that "it would seem impossible to classify stars on a scale of temperature alone."

Studies of Special Stars.—Professor E. C. Pickering communicates two lists of stars having peculiar spectra, and also a table of spectra of known variables (*Harvard Circular*, Nos. 92 and 98; *Astroph. Jour.* xxi. 292 and xxii. 87).

Herren Ludendorff and Eberhard describe (*Ast. Nach.* **170**, 165) remarkable peculiarities observed in the spectrum of ζ *Boötis.*

Sir Norman Lockyer remarks upon the spectrum of μ *Centauri* (*Proc. R. S.* lxiv. 548).

Radial Velocity of Stars.—Professor H. C. Lord (*Astroph. Jour.* xxi. 297) gives results for thirty-two stars studied at the Emerson McMillin Observatory.

Mr. Slipher (*Astroph. Jour.* xxii. 318) has given evidence of the efficient nature of the spectrograph at the Lowell Observatory. In a list of results for ten stars selected in the plan of co-operation between various observatories he gives also a summary of results obtained by different observers. In a further note (*Astroph. Jour.* xxii. 84) he publishes a summary of observations of the variable velocity of γ *Geminorum.*

Mr. Newall (*Monthly Notices R.A.S.* lxv. 651) summarises the results obtained at Cambridge Observatory for nine selected stars in 1903.

M. Belopolsky (*Astroph. Jour.* xxi. 55) gives details of measurements of photographs of α *Boötis.*

Variable Radial Velocity.—The Lick Observatory *Bulletin*, No. 79, contains, under the title "First Catalogue of Spectroscopic Binaries," a list of 140 star systems of which the composite nature had been discovered or verified by spectroscopic observations before 1905 January 1. In a final note reference is made to four other discoveries made after that date. The catalogue contains details of magnitude and spectral type of each of the stars named; period and other orbital data are given for about fifty stars. The notes as to discoverer and references which complete the data show what a splendid contribution the Lick observers have made to our knowledge of these multiple systems.

Professor Campbell and Mr. H. D. Curtis give details (*Astroph. Jour.* xxi. 185) of variable velocity for α *Andromedæ*, ζ *Ceti*, γ *Geminorum*, α_2 *Geminorum*, η *Boötis*, ξ *Serpentis*, ζ *Lyræ*, τ *Sagittarii*, and 71 *Aquilæ*. The same authors give further information (*Astroph. Jour.* xxi. 191) relating to *Polaris*, η *Piscium*, ϵ *Aurigæ*, and β *Orionis.*

Professor Campbell contributes (*Astroph. Jour.* xxi. 176) a very interesting note on the variable velocity of *Sirius.*

Mr. W. H. Wright gives (*Astroph. Jour.* xxi. 371) notes of variable velocity detected in the Southern Hemisphere in the case of α *Phœnicis*, γ *Phœnicis*, θ_1 *Eridani*, *X Eridani*, δ *Columbæ*, *A Carinæ*, σ *Puppis*, α *Puppis*, α *Volantis*, α *Carinæ*, κ *Velorum*, and *p Velorum.*

Professor Frost gives a note (*Astroph. Jour.* xxii. 213) on observations of certain variable stars (chiefly of the *Algol* type), viz. *R Canis Majoris*, *Z Herculis*, *U Sagittæ*, *U Ophiuchi*, *RX Herculis*, *Y Cygni*, and *R Coronæ*.

Mr. R. H. Curtiss contributes a note (*Astroph. Jour.* xxii. 274) on the light- and velocity-curves of *W Sagittarii*.

Mr. Slipher in a note (*Astroph. Jour.* xxii. 84) deals with the velocity of γ *Geminorum*.

Professor W. H. Julius makes (*Astroph. Jour.* xxi. 286) a new suggestion, from the point of view of anomalous dispersion, about the appearance of variation in the velocity of δ *Orionis*.

Orbits of Spectroscopic Binaries.—Mr. W. S. Adams has calculated (*Astroph. Jour.* xxii. 115) the orbit of ζ *Tauri* from twenty-five spectrographic determinations of its velocity at the Yerkes Observatory.

Solar Parallax from Spectrographic Observations of Stars.—Professor Küstner has deduced (*Ast. Nach.* **169**, 241) a value of the solar parallax from eighteen spectrograms of *Arcturus*, obtained at the Bonn Observatory with a spectrograph attached to the 12-inch equatorial. The value obtained is $8''{\cdot}844 \pm 0''{\cdot}017$.

Standards of Wave-length.—At the meeting of the International Union for Co-operation in Solar Research, held at Oxford, 1905 September 27–29, it was decided to embark upon a series of new determinations of standard wave-lengths (*Astroph. Jour.* xxii. 276).

New Spectrographic Installation.—Mr. Newall (*Monthly Notices R.A.S.* lxv. 636) describes the four-prism spectrograph which has been used at Cambridge Observatory for stellar work since 1899.

Design of Stellar Spectrographs.—In a paper on "The Optics of the Spectroscope" (*Astroph. Jour.* xxi. 197) Professor Schuster deals with the question of slit width, purity of spectrum, and intensity.

In a paper on the design of spectrographs for large equatorials (*Monthly Notices R.A.S.* lxv. 608) Mr. Newall gives details of the diffractional method of estimating slit-widths; and after dealing with the effects of atmospheric tremor on star images he considers the question of the brightness of the photographed spectra under specified conditions of purity and linear dispersion with equatorials of different aperture.

Interpretation of Spectra.—A paper of high interest and importance has been published by Professor A. Schuster on Radiation through a foggy atmosphere (*Astroph. Jour.* xxi. 1). The author takes account not only of absorption but also of scattering of light.

H. F. N.

List of Public Institutions and of Persons who have contributed to the Library, &c., since the last Anniversary.

His Majesty's Government in India.
His Majesty's Secretary of State for the Colonies.
His Majesty's Secretary of State for India.
The Lords Commissioners of the Admiralty.
The French Government.
The Italian Government.
British Association for the Advancement of Science.
British Astronomical Association.
British Horological Institute.
Geological Society of London.
Meteorological Office.
National Physical Laboratory.
Physical Society of London.
Royal Geographical Society.
Royal Institution of Great Britain.
Royal Meteorological Society.
Royal Observatory, Greenwich.
Royal Photographic Society of Great Britain.
Royal Society of London.
Royal United Service Institution.
Society of Arts.
Solar Physics Observatory.
University College, London.
Birmingham, Midland Institute Scientific Society.
Cambridge Observatory.
Cambridge Philosophical Society.
Cardiff, Astronomical Society of Wales.
Chatham, Royal Engineers' Institute.
Dublin, Royal Irish Academy.
Dublin, Royal Society.
Galway, Queen's College.
Leeds Astronomical Society.
Liverpool Astronomical Society.
Liverpool Literary and Philosophical Society.
Liverpool Observatory.
Manchester Literary and Philosophical Society.
Oxford, Clarendon Press.

Oxford University Observatory.
Rugby School Natural History Society.
Stonyhurst College Observatory.
Truro, Royal Institution of Cornwall.
Abbadia Observatory.
Adelaide, Government Observatory.
Algiers Observatory.
America, Astronomical and Astrophysical Society.
Amsterdam, Dutch Eclipse Committee.
Amsterdam, Royal Academy of Sciences.
Arcetri, Royal Observatory.
Australasian Association for the Advancement of Science.
Basel University.
Batavia, Royal Magnetical and Meteorological Observatory.
Batavia, Royal Society of Natural History.
Berlin, German Physical Society.
Berlin, Institute of Computation of the Royal Observatory.
Berlin, Royal Observatory.
Berlin, Royal Prussian Academy of Sciences.
Berne University.
Bologna, Royal Academy of Sciences.
Bologna, University Observatory.
Bombay Branch of the Royal Asiatic Society.
Bordeaux Observatory.
Bordeaux, Society of Physical and Natural Sciences.
Boston, American Academy of Arts and Sciences.
Brisbane, Royal Geographical Society of Australasia.
Brussels, Belgian Astronomical Society.
Brussels, Royal Academy of Sciences of Belgium.
Buda-Pesth, Hungarian Academy of Sciences.
Calcutta, Asiatic Society of Bengal.
Canada, Department of Marine.
Canada, Geological Survey.
Cape of Good Hope, Royal Observatory.
Cape Town, South African Philosophical Society.
Catania, Italian Spectroscopic Society.
Catania, Royal Observatory.
Charkow, University Observatory.
Cherbourg, National Society of Sciences.
Christiania, Norwegian Geodetic Commission.
Cincinnati Observatory.
Coimbra, Polytechnic Academy.
Colorado College Observatory.
Copenhagen Observatory.
Copenhagen, Royal Danish Academy of Sciences.
Cracow, Academy of Sciences.
Dijon, Academy of Sciences.
Egypt, Survey Department.

Geneva Observatory.
Geneva, Society of Physics and Natural History.
Göttingen, Royal Observatory.
Göttingen, Royal Society of Sciences.
Granada Observatory.
Groningen, Astronomical Laboratory.
Hamburg Observatory.
Harvard College Astronomical Observatory.
Heidelberg, Astrophysical Observatory.
Helsingfors, Central Meteorological Institute.
Helsingfors, Finnish Society of Sciences.
Hong Kong Observatory.
India, Survey Department.
International Bureau of Weights and Measures.
International (Central) Geodetic Bureau.
Kalocsa, Haynald Observatory.
Kasan, Imperial University.
Kiel, University Observatory.
Kodaikánal Observatory.
Königsberg, Royal University Observatory.
Leiden Observatory.
Leipzig, Astronomical Society.
Leipzig, Royal Society of Sciences of Saxony.
Lick Observatory.
Lisbon Observatory.
Lowell Observatory.
Lund, Astronomical Observatory.
Madrid, Astronomical Observatory.
Madrid, Royal Academy of Sciences.
Manila, Philippine Weather Bureau.
Mauritius, Royal Alfred Observatory.
Melbourne Observatory.
Milan, Royal Observatory.
Missouri University, Laws Observatory.
Moncalieri Observatory.
Montpellier, Academy of Sciences.
Moscow, Imperial Society of Naturalists.
Munich, Royal Bavarian Academy of Sciences.
Naples, Royal Academy of Sciences.
Natal Observatory.
New York, Columbia College Observatory.
Nice Observatory.
Nova Scotian Institute of Sciences.
O-Gyalla, Central Meteorological and Magnetical Observatory.
Ottawa, Royal Society of Canada.
Padua, Astronomical Observatory of the University.
Palermo, Royal Observatory.
Paris, Academy of Sciences.
Paris, Astronomical Society of France.

Paris, Bureau of Longitude.
Paris, École Polytechnique.
Paris, International Astrophotographic Congress.
Paris, Mathematical Society of France.
Paris Observatory.
Paris, Philomathic Society.
Perth Observatory, Western Australia.
Philadelphia, American Philosophical Society.
Philadelphia, Franklin Institute.
Philadelphia University, Flower Observatory.
Pola, Imperial Hydrographic Office.
Potsdam, Central International Geodetic Bureau.
Potsdam, Royal Prussian Geodetic Institute.
Prague, Imperial Observatory.
Pulkowa Observatory.
Rio de Janeiro Observatory.
Rome, Italian Society of Sciences.
Rome, Royal Academy dei Lincei.
St. Petersburg, Imperial Academy of Sciences.
San Fernando, Observatory of Marine.
San Francisco, Astronomical Society of the Pacific.
Santiago, National Astronomical Observatory.
São Paulo, Sociedade Scientifica.
Stockholm Observatory.
Stockholm, Royal Swedish Academy of Sciences.
Strassburg, Imperial University Observatory.
Sydney Observatory.
Tachkent, Astronomical and Physical Observatory.
Tacubaya, National Astronomical Observatory.
Tokyo, Astronomical Observatory.
Toronto, Canadian Institute.
Toronto, Royal Astronomical Society of Canada.
Toronto University.
Toulouse, Academy of Sciences.
Toulouse, Astronomical Observatory.
Transvaal Meteorological Department.
Turin, Royal Academy of Sciences.
Turin, Royal Observatory.
Uccle, Royal Observatory of Belgium.
United States Coast and Geodetic Survey.
Upsala Observatory.
Upsala, Royal Society of Sciences.
Utrecht, Royal Meteorological Institute.
Vienna, Imperial Academy of Sciences.
Vienna Imperial Geodetic Bureau.
Vienna, Imperial Military Geographical Institute.
Vienna, Imperial University Observatory.
Vienna, Von Kuffner Observatory.
Wanganui Astronomical Society.
Washington, Carnegie Institution.

Washington, Navy Department.
Washington, Philosophical Society.
Washington, Smithsonian Institution.
Washington, United States Naval Observatory.
Yale University, Astronomical Observatory.
Yerkes Observatory.
Zürich, Central Meteorological Institute of Switzerland.
Zürich, Natural History Society.
Editors of the "American Journal of Mathematics."
Editors of the "American Journal of Science."
Editor of the "Astronomical Journal."
Editor of the "Astronomische Nachrichten."
Editors of the "Astrophysical Journal."
Editor of the "Athenæum."
Editors of the "Bulletin des Sciences Mathématiques."
Editor of the "English Mechanic."
Editor of "Himmel und Erde."
Editor of "Indian Engineering."
Editor of "Nature."
Editor of "Naturwissenschaftliche Rundschau."
Editors of "The Observatory."
Editors of "Popular Astronomy."
Editor of "Sirius."

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ADDRESS

Delivered by the President, Mr. W. H. Maw, on presenting the Gold Medal of the Society to Professor W. W. Campbell.

The Gold Medal of the Royal Astronomical Society has this year been awarded to Professor William Wallace Campbell "for his spectroscopic researches, which have greatly increased our knowledge of stellar motions"; and it is my pleasant duty to-day to lay before you some particulars of the work which our Medallist has carried on with such persistent energy, and with most marked success, for so many years past.

The determination of stellar velocities in the direction of the line of sight is a branch of astronomical research which has engaged the attention of such a comparatively small band of workers that I may perhaps be allowed—even when speaking to an audience like the present—to devote a few moments to a brief sketch of its history and development. As is well known, the determination of radial velocities depends upon the fact, pointed out by Doppler as long ago as 1842, that the wave-length of light reaching the eye is affected by the motion of the source of light in the radial direction. A few years later, in 1848, Fizeau showed that the lines of the spectrum could be turned to account to determine the changes of refrangibility due to motion of the light source; but it was not until 1866 that steps were taken to utilise this fact for the measurement of stellar velocities in the line of sight. In that year the matter was taken in hand by Sir William Huggins; and having in the following year succeeded in devising and constructing suitable instrumental arrangements, he was able in 1868 to contribute to the Royal Society a paper giving the results of observations on the displacement of the F line in the spectrum of *Sirius*, thus laying the foundations of a new branch of astronomical research, which has since yielded such valuable and far-reaching results.

In 1871 observations of radial velocity were taken up by Vogel at Bothkamp, while Huggins continued to improve his equipment and increase the number of stars observed by him. The work was also taken up at Greenwich, where many observations were made by Maunder, and at Rugby, by Seabroke. In all these cases the observations were made visually, and the

difficulties attendant upon the measurement of the shift of the lines were so great that the results obtained varied very widely, and it was felt generally that the velocities deduced were not such as to inspire entire confidence in their accuracy.

This state of affairs continued until, in 1888, a very decided step in advance was made at Potsdam by H. C. Vogel, who, in place of continuing the visual observations, arranged to measure the displacement of lines in stellar spectra which had been recorded by photography. This change in the mode of working possesses many important advantages. By the use of prolonged exposures it renders available for measurement faint spectra with which it would be practically impossible to deal visually; while the measures can be made at leisure, under convenient conditions, and can be repeated as desired. On the other hand, the photographic method of working has difficulties of its own of no mean order, and the attainment of successful results by it involves in a very high degree the possession of skill, experience, and patience on the part of the worker.

One of the earliest results of the employment of the photographic method of observing stellar spectra was the discovery of the class of stars now generally known as spectroscopic binaries. For convenience it is common to speak of these binaries as divided broadly into two classes: namely, first, those in which each of the components is sufficiently bright to yield a spectrum which can be observed and measured; and, second, those in which one of the components is either dark, or so faint that the spectrum of one only of the components can be recorded with the instruments available. Strictly, of course, these two classes are not distinct, there being all gradations of intermediate pairs, representing different proportions of brilliancy of the two components; but the classification has, nevertheless, its convenience, as it indicates the difference in the methods by which the pairs can be observed. In stars of the first class the difference between the movements in the line of sight of the two components is indicated by the shift of the lines of one spectrum relatively to those of the other; and the measurement of this shift (and consequently of the radial movement corresponding to it) is thus quite independent of the radial motion which the system as a whole may have relatively to the Earth. Pairs of this class can thus be observed by the aid of slitless spectroscopes, such as the object-glass prism, the orbital motion of the two components being indicated by the periodical doubling and undoubling of certain lines in their spectra.

In the case of the second class of spectroscopic binaries, on the other hand, the determination of the orbital motion depends upon the measurement of the variable radial motion of the bright component in the line of sight relatively to the Earth; and this necessitates a comparison of the stellar spectrum with the spectrum of an artificial source, in order that the shift of certain lines, due to the radial motion of the star, may be

measured. It is evident, of course, that unless the motion of the star at any given moment relatively to the Earth can be ascertained with a high degree of accuracy, it will be quite useless to attempt to deduce the orbital motion of a spectroscopic binary from any variation in such measured movement. The development of this branch of spectroscopic astronomy has thus only been secured by the gradual introduction of various instrumental refinements, combined with the recognition of the sources of error, and the exercise on the part of the observers of care and skill of the very highest order. Amongst those who have contributed to this progress none are entitled to a higher place than he to whom your medal has this year been awarded. Of course the discovery of spectroscopic binaries is in no sense the primary object of the measurement of radial velocities; but the fact that binary pairs of this second class can now be effectively dealt with is in itself a proof of the advances which have been made.

The first spectroscopic binary to be discovered was ζ *Ursæ Majoris*. In the third Annual Report of the Henry Draper Memorial, issued in 1889, Professor Pickering called attention to the fact that in the spectra of the star photographed at Harvard the K line occasionally appeared double. Photographs of the spectrum taken at intervals extending from 1887 March to 1889 October were carefully examined by Miss A. C. Maury; and eventually evidence was obtained pointing clearly to the conclusion that this doubling of the K line was due to the orbital motion of a pair of bodies giving spectra of the same type and of approximately equal brightness. ζ *Ursæ Majoris* thus belongs to the first-named class of spectroscopic binaries, and its discovery was closely followed by a second—namely, that of β *Aurigæ*, Miss Maury announcing, late in 1889, that lines in the spectrum of this star became alternately double and single every forty-eight hours, thus giving the pair a period of four days.

The first spectroscopic binary of the second class to be discovered was *Spica* (α *Virginis*), the duplicity of which was announced in 1890 by Dr. Vogel, who had during the previous year determined spectroscopically variations in the radial velocity of *Algol* (β *Persei*), and had thus endorsed the deduction of its binary character founded on observations of its varying luminosity. From that time the discovery and examination of close binary systems by spectroscopic means have gone steadily on, and admirable work has been done, notably in Europe, by Vogel and Scheiner at Potsdam, Belopolsky at St. Petersburg, Newall at Cambridge, and Deslandres at Meudon; and on the other side of the Atlantic by Professor Pickering and his colleagues at Harvard, by Frost and Adams at the Yerkes Observatory, by Slipher at the Lowell Observatory, and lastly—but in this case certainly very far from least—by Professor Campbell and his colleagues at Mount Hamilton. At the present date the number

of known spectroscopic binaries amounts to some 146, and of these nearly one-fourth have, as we shall see later, been discovered by our Medallist personally.

The measurement of stellar velocities in the line of sight by visual methods was taken up at the Lick Observatory some fifteen years ago, when measures were made by the late Professor Keeler, and subsequently by Professor Campbell and Dr. Crew. It was at this period that the late Professor Keeler made, with a grating spectroscope, his magnificent series of measures of the radial velocities of fourteen nebulæ. This work was of the highest order, but the feebleness of light for visual measures led to work in this branch of research being discontinued; and the determination of radial velocities cannot be said to have formed an item in the regular programme of work at Mount Hamilton until the construction of the Mills Spectrograph in 1895. The installation of this spectrograph, as well as its partial reconstruction some six years later in accordance with the experience then acquired, was rendered possible by the generosity of Mr. D. O. Mills; and in designing it Professor Campbell determined to sacrifice any considerations which would interfere with its convenience and efficiency for the determination of stellar velocities in the line of sight, using the $H\gamma$ region of the spectrum. It would be impossible—even if it were desirable—in the time available to-day, to give anything like a detailed description of the Mills Spectrograph, and I must, therefore, confine myself to a few brief notes concerning it.

The Lick telescope has a clear aperture of 36 inches and a focal length of 58 feet, the focal length for the $H\gamma$ rays, however, being 1·9 inches longer than for the D rays, a fact which affected a certain feature in the design of the spectrograph, as will be seen later. The collimator of the spectroscope has a double lens of Jena glass, 1·78 inches clear aperture stopped down to 1·5 inches, and a focal length of 28·4 inches. It gives a circular beam of $H\gamma$ light, 1·5 inches in diameter, received by a train of three dense flint prisms of such density and angle as to give a total deviation of about 180 degrees.

As regards resolving power, the instrument has been found fully capable of realising the theoretical limits appropriate to its proportions. In the case of the solar spectrum the observed purity has for practicable slit widths been found somewhat greater than its computed value; while in the case of some stellar spectra photographed on rapid plates, with a slit-width of 0·02 millimetre, lines $\lambda\lambda$ 4337·216 and 4337·414 are shown separated; the difference in wave length—namely, 0·198 tenthmetre—being in these instances exactly the theoretical limit for the width of slit used.

The steepness of the colour curve of the object-glass of the Lick telescope, to which I have already referred, led to a difficulty in the guiding of the instrument when the spectrograph was in use. With the slit placed on the $H\gamma$ focus, the $H\gamma$ image

of a star is a point in the centre of a comparatively large disc of light due to rays of various refrangibilities, and the central point cannot be seen with sufficient distinctness to be used for guiding. This rendered inapplicable Sir William Huggins's simple plan of using reflecting slit plates. Other known methods had disadvantages of their own, and at length, after many experiments, Professor Campbell decided to use light reflected from the first prism surface to form a guiding spectrum, this reflected light passing through a thirty-degree prism to the guiding telescope. An occulting bar in the eyepiece covers all the spectrum except the Hγ region, this region being linear as the Hγ rays are in focus on the slit. If the Hγ image fails to be on the slit, a gap occurs in the guiding spectrum. This guiding device has proved quite satisfactory.

It is the practice at the Lick Observatory to use the big telescope for spectroscopic work on three nights in each week, the remaining nights being devoted to double-star work, &c. Provision had, therefore, to be made for readily and safely attaching and detaching the spectrograph, and the arrangements for this purpose have been so well worked out that the change from micrometer to spectrograph, or *vice versa*, can be easily effected by one person in six minutes.

I have said that the determination of the radial velocities of stars by the measurement of photographed spectra is a system of working attended with special difficulties of its own, and perhaps a few figures relating to the practice at Mount Hamilton may serve to show the delicacy and accuracy necessary. With the Mills Spectrograph an exposure of about fifteen seconds, with a slit width of 0·015 millimetre, will record the spectrum of *Sirius*, but for a fifth-magnitude star about an hour's exposure with a slit width of 0·025 millimetre is necessary under average conditions. The width of the spectrum obtained is about 0·3 millimetre. The comparison spectra used are those of hydrogen and iron, an exposure of five seconds sufficing for the Hγ line, while in the case of the iron spectrum about three seconds is given for the brighter, and about sixty seconds for the faint lines, a device being provided for occulting the brighter lines after a short exposure has been made.

The measurement of the spectra is effected by a micrometer microscope, which is a duplicate of that employed at Potsdam. It has a screw of 0·25 millimetre pitch, the head being divided into 100 parts, and being capable of being read to tenths of a division. Three settings are made on each of the star lines selected for measurement, and a corresponding number on the lines of the comparison spectrum, corrections being, of course, introduced for the curvature of the spectrum lines. Speaking of these measures, Professor Campbell has said: "The extreme accuracy required and attained in this class of work is evident from the following statement: The linear value of 0·01 second of arc in the focus of the 36-inch refractor is 0·000857 millimetre.

On the spectrum plates 0·000857 millimetre is 0·0034 revolution of the screw, corresponding to 0·74 kilometre per second displacement.* It is not surprising, therefore, that great care and considerable experience are absolutely necessary for suitable measurement of the plates. The lines to be measured require good judgment in their selection. Some of the best lines in the solar spectrum are practically useless in many stars, owing to the changed intensities of close companion lines."

From the measured displacement of the stellar lines the corresponding radial velocity can be calculated, but the velocity so obtained is that of the star relative to the observer at the time of the observation; and before the motion of the star relative to the sidereal system can be ascertained four components must be eliminated. These components are due (1) to the rotation of the Earth on its axis; (2) to the revolution of the Earth round the common centre of gravity of the Earth and Moon; (3) to the revolution of the Earth round the Sun; and (4) to the motion of the solar system as a whole. For determining this last correction we are not yet in possession of sufficient data, and the practice at present, therefore, is to reduce stellar radial velocities to the Sun by the application to the observed velocities of the three first-named corrections. The application of these corrections and other calculations relating to the spectroscopic determination of velocities have been much facilitated by a valuable series of tables prepared by our Medallist.† In an introduction to these tables, Professor Campbell says: "The remarkable accuracy of recent spectroscopic observations requires that the corrections be applied to the nearest tenth of a mile (= 0·16 kilometre) per second. The still greater accuracy which may be reasonably expected in the future will require that they be applied to one-hundredth of a mile (= 0·016 kilometre) per second, and such is the limit of precision adopted in these tables." The success which has attended our Medallist's own work in this direction seems to amply warrant the forecast made in the words I have just quoted.

The Mills Spectrograph was first used in 1895 May, but it was nearly a year later before all adjustments had been completed and sources of error eliminated. Between the summer of 1896 and the end of 1900 some 2000 spectrograms were obtained, these including some 1500 spectrograms of 325 stars situated between the North Pole and declination −30 deg. Of these last-named spectrograms between 300 and 400 related to spectroscopic binaries, nearly fifty plates being required for the investigation

* In other words, the displacement of a line corresponding to a velocity in the line of sight of 1 kilometre per second is equal to about $\frac{1}{865}$th of a millimetre, or, say, $\frac{1}{21800}$th of an inch.

† *Astronomy and Astrophysics*, vol. xi. p. 319. The Tables, modified to suit the adoption of the kilometre as the unit of velocity per second, are also given in Frost's translation of Scheiner's *Treatise on Astronomical Spectroscopy*, p. 338

of ζ *Geminorum* alone. Since that time the work has gone on steadily and with ever-increasing accuracy, and in April last year Campbell was able to bring out the first published catalogue of spectroscopic binaries: a catalogue which is in itself ample evidence of the importance of the work done by our Medallist.

From this catalogue it will be seen that at the end of 1904 140 spectroscopic binaries were known, and of these no less than fifty-eight had been discovered by the aid of the Mills Spectrograph at the Lick Observatory, and fourteen by the D. O. Mills Expedition to the Southern Hemisphere, making seventy-two, or more than half the total, discoveries stand to the credit of the Lick Observatory staff. The more recently constructed Bruce Spectrograph of the Yerkes Observatory makes an excellent second, with forty-one discoveries to its credit. Of the fifty-eight spectroscopic binaries discovered at Mount Hamilton up to the end of 1904 no less than half—twenty-nine—were discovered by Campbell himself, and five more by Campbell working in conjunction with another observer. During 1905 the number of binaries recorded in the catalogue just referred to has been increased by six, of which three have been discovered at the Yerkes Observatory, two at Mount Hamilton, and one at the Mills Observatory, Santiago. Up to the present the radial velocities of some 500 stars have been determined at Mount Hamilton, and of about 200 more by the D. O. Mills Expedition to Chile, and the whole of this extensive and most important work has been inaugurated by our Medallist, and carried out—much of it by himself personally—in accordance with the programme which he had drawn up.

Nor is the importance of our Medallist's work on the determination of radial velocities and the characteristics of spectroscopic binaries to be judged simply, or even chiefly, by its amount. Of even greater value is the influence which he has personally exerted on the accuracy of observations of radial velocity. Writing on this point in 1904, in the publications of the Yerkes Observatory, Professors Frost and Adams said: "The next great advance was made by Campbell, in his design of, and work with, the Mills Spectrograph of the Lick Observatory. . . . The use of iron as a comparison spectrum (previously tried by Vogel and Deslandres, but not regularly employed by them), together with the closest attention to the optical and mechanical construction of the instrument, and great refinement in the measurement of the plates, enabled Campbell to increase greatly the accuracy of the determinations; so that the natural unit became the kilometre per second, instead of the sevenfold greater German geographical mile employed by Vogel."

Our Medallist's views as to the future development of this branch of spectroscopic work are naturally of great interest. Up to the end of 1904, he tells us, at least one in seven of the stars examined by the Mills Spectrograph appears to be an

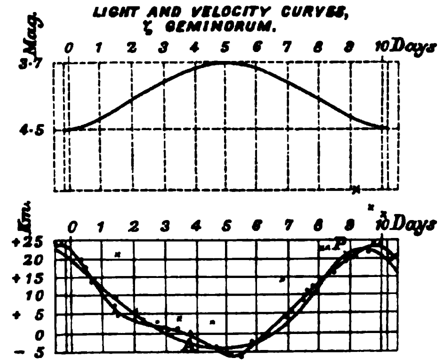
invisible binary of short period. In the case of the Bruce Spectrograph at the Yerkes Observatory, where stars of the "Orion" type have been especially studied, the proportion of binaries has been much greater—namely, about one in three.

It must be remembered, however, that the spectroscopic binaries, so far discovered, are naturally those having relatively short periods, and showing therefore considerable variations in velocity, the smallest variation so far recorded as showing a binary character being in the case of *Polaris*, namely, 6 kilometres per second. But much smaller variations than this may really be indicative of orbital motion; and there is every probability that, as time goes on and data accumulate, spectroscopic binaries may be numbered by thousands. One limit to our present investigations lies in the enormous loss of light in passing through a train of prisms, and in the fact that in the spectrum the light of a star is spread over a comparatively large area. Professor Campbell regards the 8th magnitude as probably the smallest which can be successfully observed by existing appliances, and he considers that obtaining the spectrogram of a 9th magnitude star using only moderate dispersion is comparable with photographing a 20th magnitude star by the aid of our most powerful reflecting telescopes.

If time permitted much could be said respecting the special features of many of the spectroscopic binaries which have been discovered by our Medallist, but I must content myself with some brief notes on three only. The first of these is ζ *Geminorum*, a well-known variable, which I have already had occasion to mention. Its binary character was discovered by Belopolsky in 1898 January, but no announcement of the discovery appears to have been published, and the duplicity of the star was independently discovered by Professor Campbell in 1899 January, and announced by him the following month. Between 1898 November and 1900 February forty-four spectrograms of ζ *Geminorum* were secured at Mount Hamilton, and these were duly measured and reduced, with the result that they showed clearly that the pair had an orbital movement corresponding to the period of its light curve—namely, 10·154 days, the observed velocity in the line of sight varying from +24·2 to −6·7 kilometres per second.

The diagram on page 253 shows in the upper figure the light curve of ζ *Geminorum*, and in the lower figure the radial velocities, the thick line showing the velocities as observed, and the thin line the velocities corresponding to an elliptic orbit, which Professor Campbell selected as affording probably the best possible elliptic representation of the observed curve. The observations extend over forty-five complete periods, and it will be noted that the two curves intersect six times during a period. Professor Campbell has remarked that the disturbances in the observed curve might be explained by assuming that ζ *Geminorum* was a triple system, but he considers that they are more

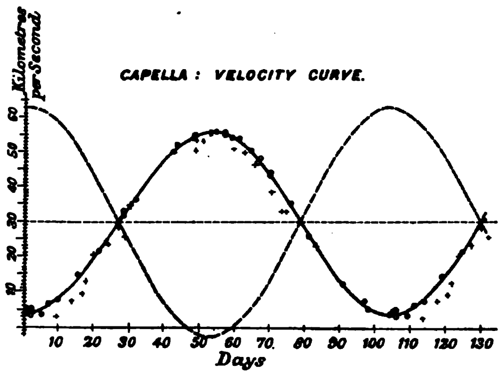
probably due to tidal effects caused by the comparative proximity of the two components revolving in an eccentric orbit.



The next spectroscopic binary which I shall mention, namely, *Capella*, has a special interest for British astronomers, inasmuch as its binary character was discovered independently by our Medallist at Mount Hamilton and by Mr. Newall at Cambridge within a very brief period, Professor Campbell making his announcement at the meeting of the Astronomical and Astrophysical Society of America in 1899 September, while Mr. Newall submitted a note on his discovery at the meeting of our Society in November of the same year. During 1900 also the pair was observed with the 28-inch equatorial at Greenwich, and a number of micrometer measures were made, with results pointing to an orbit closely agreeing with that deduced from spectrographic observations.

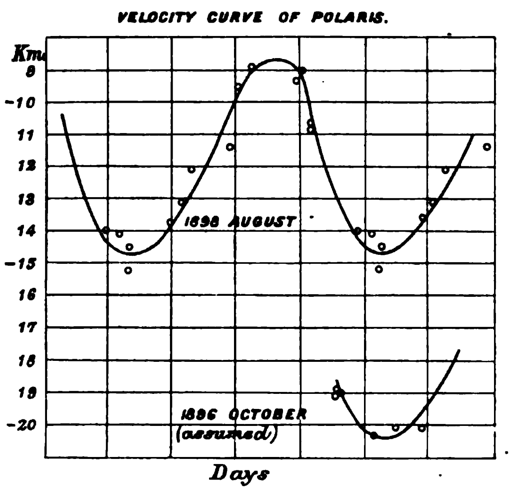
According to Professor Campbell the spectra of the two components are distinguishable on most of the spectrographs taken, that of the principal star being of the solar type, and that of the other something between the solar and Sirian types, and the presence of the latter spectrum adds materially to the difficulties of measuring that of the chief component. From data based on thirty-one spectrographs taken between 1896 September and 1900 September Campbell deduced for the chief component a range of velocity in the line of sight from $+4{\cdot}2$ to $+55{\cdot}7$ kilometres per second, and for the second component a range from -3 to $+63$ kilometres per second; while for the velocity of the centre of mass of the system he arrived at the value $+30$ kilometres per second. On computing the orbit, the period determined as best agreeing with the observations was one of $104{\cdot}1$ days, the orbit having an eccentricity of $0{\cdot}02$. The diagram on page 254 records these figures, and shows the computed velocity curve, abscissæ representing times and ordinates velocities in the line of sight, while the dotted horizontal line indicates the velocity of the centre of mass. The dotted curved

line indicates, approximately, the variable radial velocity of the lesser component.



On the diagram the Mount Hamilton observations are represented by circles, while Mr. Newall's observations are plotted as crosses; and it will be seen that a small reduction in the velocity of the centre of mass would bring the two sets of observations into fair agreement. I should add that Mr. Newall's computation of the probable orbit, as given in his paper published in *Monthly Notices* for 1899 November, also gives a period of 104 days.

The last spectroscopic binary to which time will permit me to refer in any detail is *Polaris*, a star the motion of which is marked by some very special features. Between 1896 Septem-



ber 8 and December 8 six spectrograms of *Polaris* were obtained by Campbell, and these gave very consistent results, the mean

radial velocity deduced being one of −19·6 kilometres per second. In 1899 August, however, another spectrograph gave a velocity of −13·1 kilometres per second, and this led to a further series of observations being made, with the result that between 1899 August 9 and 30 velocities varying from −8·6 to −15·2 kilometres per second were obtained. On plotting these results it was clearly indicated—as shown by the diagram on page 254—that *Polaris* was a binary with a period of rather less than four days. The diagram also shows the 1896 results, and the discrepancy between these and the observations of 1899 remained to be explained. Since 1899 *Polaris* has been regularly observed spectroscopically at Mount Hamilton, and the results of these observations are given in the table subjoined, which also includes the results of 1896 and 1899.

Observations of Polaris at the Lick Observatory.

Date.	Velocities in the Line of Sight at Positions of Minima. Kilometres per Second.
1896·9	−20·67
1899·8	−14·22
1900·6	−14·64
1901·4	−16·32
1902·6	−16·79
1903·0	−17·18
1903·7	−17·84
1904·5	−18·52

Professor Campbell's deduction from his observations is that *Polaris* is a triple system, the rapid pair having a period of 3 days 23 hours 14 minutes, and that the velocity of the centre of mass of this pair is changing along a velocity curve corresponding to a period of at least eleven years, but which may be considerably longer. It is evident that some years must still elapse before any really definite determination of this longer period can be arrived at, but meanwhile the progress of the observations at Mount Hamilton will be followed with the greatest interest.

By the year 1901 our Medallist had accumulated enough data relating to radial velocities to justify him in utilising his results for a first rough determination of the Sun's way. For this purpose he used the motions of 280 stars, and these he divided into eighty groups, the mean of the velocities of the stars forming a group being taken as the velocity of that group. Equations of condition were obtained for the eighty groups, each equation being weighted in proportion to the number of stars contained in the group to which it referred, and the eighty equations were then combined and solved by the method of least

squares. The position thus obtained for the apex of the Sun's way was R.A. 277° 30′ and declination +19° 58′, while the Sun's velocity was 19·89 kilometres per second. The right ascension thus found agrees exactly with Newcomb's, and differs only 1½° from Kapteyn's, but in the value of the declination there is a material divergence, Newcomb's declination being 15° and Kapteyn's 14° greater. This result is attributed by Campbell to the extremely unsymmetrical disposition of the groups of stars used in his determination, there being a great dearth of Southern stars—a deficiency which gave rise to the Mills Expedition to Santiago. The organisation of this expedition may well be cited as a splendid example of the thoroughness and vigour with which our Medallist attacked an important problem. Notwithstanding its admitted preliminary character, this determination of the Sun's way by Campbell is of great interest; and we must all hope that as soon as suitable data have accumulated the work may again be taken in hand by our Medallist. It may be mentioned, by the way, that only last month Mr. H. D. Curtis left Mount Hamilton with his family, to carry on another five years' work in Chile.

The investigation of the solar motion to which I have just referred brought out some interesting facts which I may mention here. One of these was that the average velocity of the stars dealt with was 26·78 kilometres per second in a plane at right angles to the line of sight, while *in space* the average velocity was 34·10 kilometres per second. The deduced velocity for the Sun—namely, 19·9 kilometres per second—was therefore very much smaller than that of the average star of the system.

Another interesting deduction, drawn by our Medallist, concerned the relation between velocity in space and the visual brightness of the stars used in this investigation. Dividing these stars into three groups, of which the first consisted of stars of the third magnitude or brighter, the second of the stars between 3·1 and 4·0 magnitude, and the third of stars fainter than magnitude 4·0, Campbell obtained for the average velocities of the stars in these groups the figures 26·1, 32·3, and 38·88 kilometres per second respectively. This result, which Campbell considers to be in no way due to probable errors of observation, is a very important one, affecting as it does our ideas as to the relation between the proper motion and distance of stars, and it well deserves further examination.

I have devoted considerable time to remarks on the observation of spectroscopic binaries, and the determination of stellar velocities in the line of sight, because these are branches of work with the development of which Campbell has been so prominently and so honourably associated; but our Medallist has many other strong claims for recognition at our hands, and to some of these I must proceed to direct attention.

During the latter part of 1893 and the first half of 1894 Campbell devoted much time to a thorough examination of such

stars of the Wolf-Rayet type as were observable at Mount Hamilton. The immediate object of the work was to determine whether there was any analogy between these stars and the new star in *Auriga*, and it resulted in the discovery of many points of interest. It would be impossible in this Address to deal with these matters in any detail, but a few features may be mentioned. One point—at that time novel, but since well established—which came out strongly was the great variety of form and intensity assumed in these spectra by lines belonging to the same element. This was particularly the case with the hydrogen lines, which were found some dark and some bright, in different parts of the same spectrum: the dark hydrogen lines in some cases having bright borders, as if doubly reversed, while the bright lines varied from monochromatic lines to broad bands, being in some instances clearly single, and in others apparently multiple. Campbell's observations of spectra, including both dark and bright hydrogen lines, led him to the conclusion that in stars giving such spectra the bright lines are, as a rule, those of greater wave length, and the dark lines those of shorter wave length. Schuster has recently given theoretical grounds for accepting this as possible. Another conclusion is, that the intensities of the bright lines decrease, and those of the dark lines increase, towards the violet end of the spectrum.

Another interesting result was the discovery of a star surrounded by an envelope of hydrogen. This star—which was discovered at Harvard in the course of the Draper Memorial Surveys—is D.M. 30°, 3639, and is of below the 10th magnitude. It nevertheless yields a spectrum which is easily observable on account of the sharpness of its lines, of which 30 were measured by our Medallist in 1893, some of them appearing to be individual to this particular star. The great feature of interest was the behaviour of the $H\beta$ line. To quote Campbell's own words: "When the spectroscope was adjusted for the various parts of the spectrum the line at λ 5694 appeared essentially as a stellar point; the band at λ 4652 was broad but short, and lay wholly upon the continuous spectrum; but the line $H\beta$ was narrow and long, extending a very appreciable distance on each side of the continuous spectrum. When the slit was opened wide the $H\beta$ line became a circular disc, while the line λ 5694 and the band λ 4652 remained unchanged." The diameter of this disc was subsequently measured by the micrometer, and found to be about 5″. Campbell's observations of this star were confirmed by Runge in 1897, and by Keeler in 1898. Other stars of similar type have been examined for discs, but, so far as I am aware, this star remains up to the present a unique example of its class.

In connection with the variable behaviour of hydrogen lines, reference may be made here to the interesting observations of *Mira*, carried out by Campbell during the very favourable maximum of 1898. This star, as is well known, has a dark line

spectrum of Secchi's third type with bright hydrogen lines Hγ, Hδ, Hζ, Hη, &c., and it was first examined with the Mills Spectrograph solely for the purpose of determining its velocity in the line of sight. Observations were made in 1897 and 1898, and measures of the dark line spectrum gave a fairly constant velocity of recession of 62·5 kilometres per second. But a comparison of the dark line with the bright line spectrum showed unmistakably that the latter is displaced towards the violet with reference to the former. Owing to the great brilliancy of the Hγ band, it was over-exposed on a number of the plates taken; but on 1898 August 29 a short exposure was made which enabled the structure of the band to be analysed. It was then found to be triple, being composed of three lines of which the central one was by far the strongest, that on the violet side having an intensity of about one-half, and that on the red side of about one-fourth, the intensity of the central line. The mean wave lengths determined for the three components were 4340·24, 4340·60, and 4340·91 respectively. Shortly afterwards Mr. Wright obtained photographs of the Hδ band, and this proved to be also triple, the central line being much the strongest, and the other two about equal to each other in intensity. This band was also displaced towards the violet as compared with the dark line spectrum, and in the case of the component next the red the amount of the displacement agreed closely with that of the corresponding component of the Hγ line; but in the case of the two other components the displacement was considerably greater. About two months later further photographs were obtained of the Hγ and the Hδ bands, when it was found that their character had changed, they being then apparently single lines; moreover the former had materially shifted its position, its wave length being determined as 4340·37; while on the other hand the single Hδ line retained a position practically identical with that of the central component of the triple group observed at the earlier date. So far as the evidence at present available enables us to judge, this tripling of the bright hydrogen lines appears to only take place in the spectrum of *Mira* on the occasion of an exceptionally bright maximum, but it is to be hoped that further evidence on the point may be obtained. As to the cause of the change no explanation is as yet forthcoming, but Campbell is careful to point out that the shifting of the bright lines relatively to the dark line spectrum is not necessarily to be attributed to high velocities of incandescent hydrogen in the line of sight, but that it may be due to change of pressure or other physical causes. In any case the observations are of high interest. I may add that a visual examination of the spectrum of *Mira* by Professor Keeler, Professor Campbell, and Mr. Wright failed to show either Hα or Hβ as bright lines. Professor Campbell noted, however, that as the continuous spectrum became fainter other bright lines appeared, and two of these were apparently iron lines, and showed a displacement

towards the violet agreeing with that of the single $H\gamma$ and $H\delta$ lines.

I have, so far, dwelt almost entirely on our Medallist's work in connection with the spectroscopic examination of stellar objects; but, even at the risk of unduly extending this Address, it is desirable that I should also say at least a few words regarding his valuable contributions to other branches of spectroscopic research. On the occasion of the solar eclipse observed in India, in 1898 January, Campbell included in his programme an attempt to determine the law of rotation of the corona, by measurements of its velocity in the line of sight on opposite sides of the Sun's disc. On account of the high dispersion which it was necessary to employ, our Medallist concluded that it would be hopeless to attempt to deal with any other than the bright line portion of the coronal spectrum, and he determined, therefore, to base his observations on the green line, and not to reject the evidence afforded by even the lowest part of the corona. He further decided, after making some experiments, to employ a prism train in preference to a grating. The prism train used consisted of four compound and two single prisms, giving a combined deviation of 265° 41′.

By a highly ingenious series of shutters he was enabled to get a photographic record of the bright green line in the corona spectrum side by side with portions of the solar spectrum on the same photographic plate, and measurements showed a relative velocity in the line of sight for the east and west sides of the corona of 6·2 kilometres per second, corresponding to a rotational velocity of 3·1 kilometres per second. Campbell, however, regarded this result as subject to a possible error of ± 2 kilometres per second, partly owing to errors of observation, but chiefly owing to the character of the bright line itself, the inner ends being over-exposed and the outer ends under-exposed. Thus, while the results of the attempts to determine spectroscopically, during the eclipse of 1898, the rotational speed of the corona were not so definite as could be wished, they were eminently suggestive, and will, it may be hoped, form the foundation for further work in this direction hereafter.

Our Medallist was among those who were successful in adopting the method of employing a moving photographic plate to record the succession of phenomena during a solar eclipse; and for use during the Indian eclipse of 1898 he devised an instrument which enabled him to take successively on the same plate photographs of the spectrum of the disappearing crescent, of the corona and of the reappearing crescent. This instrument had a Rowland grating placed about 5 inches in front of a camera objective of $2\frac{5}{32}$ inches aperture and $20\frac{3}{4}$ inches focal length; and the whole of the arrangements for controlling the exposures were characterised by great ingenuity and completeness.

The first and third exposures thus made yielded results of

high interest. The transition from dark to bright lines was indicated by the first exposure very definitely, and it was shown that before the continuous spectrum ceased recording some of the dark lines apparently disappeared. In other cases the dark lines and their corresponding bright lines coexisted until the continuous spectrum ceased to form a sufficiently bright background for the dark lines. Marked anomalies were also shown in the relative intensities of different portions of the dark and bright line spectra, but on these and many other points it is impossible for me to speak on the present occasion, and I will only refer to one other feature of the first exposure which appears to be especially worthy of note. Our Medallist found that in many—but not in all—cases, where dark and bright lines coexisted, the dark lines were displaced towards the violet by as much as four- or five-tenths of a tenth-metre: this effect, however, being almost wholly confined to the first exposure, and at the time of second contact. Campbell has shown strong reasons for believing that this result is not due to any instrumental defect; while, moreover, another negative (somewhat under-exposed, unfortunately) obtained on a moving plate with another instrument—a collimating spectrograph with a radial slit—showed the same effect for Hγ and Hδ lines at both second and third contacts. Concerning the meaning of this effect Campbell says: "Assuming the reality of the displacement, we naturally consider its significance from the point of view of wave length. If this is a pressure effect, we conclude that the predominating absorption stratum for these lines is above the predominating radiation stratum. Whether this effect is general over the Sun's surface, or is purely local and confined to certain lines, is immaterial so far as the interpretation of these particular observations is concerned, provided that the pressure in the solar atmosphere increases towards the Sun's centre."

I have referred especially to Professor Campbell's work in connection with the Indian eclipse of 1898, but it must be remembered that the Indian expedition of that year is only one of many such expeditions which have had the benefit of his experience and enthusiasm. It is, in fact, impossible to overrate the importance of the influence which our Medallist has exercised on the eclipse expeditions which have during recent years been sent out from the Lick Observatory; and probably only those who have taken part in such expeditions can fully appreciate his powers of organisation, and his skill and resourcefulness in devising special lines of research and instrumental means for rendering such researches practicable.

Although I have touched upon so many instances of important work carried out by our Medallist it would be easy, did time permit, to treat of numerous other claims which he has created to recognition at our hands. Amongst these, for instance, are his researches on the spectra of nebulæ, including the comparison of the visual hydrogen spectra of the *Orion* nebula and of a

Geissler tube; his determinations—as a check on his stellar measurements—of the radial velocities of the Moon and of planets; his important work on the orbit and parallax of *Sirius*; his observations on the spectra of comets; and lastly, but by no means least, his most valuable investigations of the spectroscopic characteristics of temporary stars. Speaking of these latter researches, the Commissioners of the Académie des Sciences, MM. Lœwy, Callandreau, Wolf, Radau, Janssen and Deslandres, who in 1903 awarded to Professor Campbell the Lalande prize, said: "To him we owe the most thorough study of the numerous remarkable temporary stars of recent years; he has been able to follow to the last stages of their decline the most difficult of observation, and to recognise their more or less complete transformation into nebulæ." These observations would in themselves afford ample scope for lengthy comment, but I am compelled to pass them by with this mere mention. And now, in bringing this Address to a close, I can only express the hope that, incomplete as my record of our Medallist's work has been, it may yet suffice to indicate how greatly our science is indebted to him for important advances secured by researches most excellently planned, and carried out with a skill, persistence, and energy which command our highest admiration. That our Medallist may long be spared to continue the work he has so keenly at heart is our most earnest wish.

It is a matter of regret to us all that it has not been possible for Professor Campbell to be with us this afternoon to receive in person the medal which has been awarded to him. But in view of the fact that it is only a few months since he visited Europe, and of the important work which he has in hand at Mount Hamilton, Professor Campbell's absence, although, as I have said, a matter for regret, is not one for surprise. Moreover, we are not without a compensation. It has on many occasions been our pleasure to heartily welcome in this room Mr. Choate, for so many years the American Ambassador in this country; and now Professor Campbell's absence has afforded us the opportunity of extending an equally cordial welcome to Mr. Whitelaw Reid, who has succeeded Mr. Choate in his most important office, and who will, I am sure, also succeed him in the esteem and regard of the British nation.

There is a special fitness in Mr. Reid's presence here to-day, as I have learned that—by a peculiarly happy coincidence—he is the son-in-law of Mr. D. O. Mills, through whose munificence it was rendered possible not only to construct the Mills Spectrograph but also to organise and carry out those observing expeditions to Chile which have proved such an extremely valuable aid to Professor Campbell's scheme of research.

Mr. Reid, in handing you this medal which you have kindly undertaken to transmit to Professor Campbell I will ask you to

assure him of the very deep interest which we in England take in the important work which he is so successfully prosecuting, and to express to him our high appreciation of the influence which his researches have exerted—and still are exerting—on the development of astronomical knowledge.

The Meeting then proceeded to the election of Officers and Council for the ensuing year, when the following Fellows were elected :—

President.

W. H. Maw, Esq.

Vice-Presidents.

F. W. Dyson, Esq., M.A., F.R.S., Astronomer Royal for Scotland.
J. W. L. Glaisher, Esq., M.A., Sc.D., F.R.S.
H. F. Newall, Esq., M.A., F.R.S.
H. H. Turner, Esq., M.A., D.Sc., F.R.S., Savilian Professor of Astronomy, Oxford.

Treasurer.

Major E. H. Hills, C.M.G.

Secretaries.

Thomas Lewis, Esq.
E. T. Whittaker, Esq., M.A., F.R.S.

Foreign Secretary.

Sir William Huggins, K.C.B., O.M., LL.D., D.C.L., F.R.S.

Council.

Sir William Abney, K.C.B., R.E., D.C.L., F.R.S.
Sir R. S. Ball, M.A., LL.D., F.R.S., Lowndean Professor of Astronomy and Geometry, Cambridge.
Sir W. H. M. Christie, K.C.B., M.A., D.Sc., F.R.S., Astronomer Royal.
Bryan Cookson, Esq., M.A.
P. H. Cowell, Esq., M.A.
A. C. D. Crommelin, Esq., B.A.
Alfred Fowler, Esq., Assistant Professor of Physics, South Kensington.
A. R. Hinks, Esq., M.A.
E. B. Knobel, Esq.
Major P. A. MacMahon, D.Sc., F.R.S.
S. A. Saunder, Esq., M.A
E. J. Spitta, Esq.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

Vol. LXVI. March 9, 1906. No. 5

W. H. Maw, Esq., President, in the Chair.

Frederick Joseph William Crowe, Marsden, Chichester ;
Thomas Edward Heath, 53 Park Place, Cardiff ;
Samuel Thomas Johnson, Melrose, Bridport, Dorset ;
George Tyrrell McCaw, Geodetic Survey, North Eastern Rhodesia, South Africa ; and
Percy Alfred Talbot, B.A., F.R.G.S., F.A.I., Sapele, Southern Nigeria, West Africa,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Edmund Dickson, F.G.S., 2 Starkie Street, Preston, Lancashire (proposed by A. L. Cortie) ;
Jacob Karl Ernst Halm, Ph.D., Royal Observatory, Edinburgh (proposed by F. W. Dyson) ;
John William Hicks, Computer to the Ordnance Committee, Ordnance Committee Office, Woolwich (proposed by Sir W. H. M. Christie) ;
William Malin Hunt, engineer, 48–50 London Road, Nottingham (proposed by Samuel Fellows) ; and
Lieut. Edwin Baikie Simpson-Baikie, R.N.R., 142A, The Bluff, Yokohama, Japan (proposed by D. P. Richards).

A hundred and one presents were announced as having been received since the last ordinary meeting, including, amongst others :—

Miss A. M. Clerke, Modern Cosmogonies, presented by the author ; W. T. Lynn, Remarkable Comets and Remarkable Eclipses (new editions), presented by the author ; Paris Observatory Memoires, vol. xxiv. (Gaillot, Tables de Saturne), presented by the Observatory ; Philadelphia Observatory Publications, vol. ii., pts. 2, 3 (Measures of Double Stars &c.), presented by the Observatory ; Tōkyō Observatory Annals, vol. iii., pts. 3, 4, presented by the Observatory.

Royal Observatory, Greenwich, eight original negatives of the Sun taken 1905 October–November, and thirty-six charts of the Astrographic Chart of the Heavens, presented by the Observatory ; photographs of the Solar Eclipse of 1905 August 30, presented by Mr. E. W. Barlow ; two photographs of the Flash Spectrum, 1905 August 30, presented by Dr. S. A. Mitchell.

On the Correction to Hansen's "Tables de la Lune" as deduced by Mr. Cowell. By E. Nevill.

As Mr. Cowell has brought to a conclusion the series of papers he has been contributing for the last two years to the *Monthly Notices* on the errors of the lunar tables, as shown by the Greenwich observations since 1750, it seems fitting that one who has been working for thirty years on the subject should offer such criticism as seems necessary on the results that have been obtained in one of the most important contributions that have been made for years to the better understanding of the motion of the Moon.

(1) The methods of investigation adopted by Mr. Cowell are perfectly sound, and the apparent values of the corrections he has deduced from the observations and embodied in Table X. of his paper in the *Monthly Notices* for 1904 December appear to have been derived with accuracy in a legitimate manner. Some small errors may have been made and some mistakes overlooked ; but in so long and complicated an investigation such things are unavoidable, as I have learnt by much experience. My own investigation of the same observation, completed years ago, have afforded many facilities for testing the accuracy of Mr. Cowell's work, and have shown its freedom from important error ; and I have no hesitation in accepting the values given in Mr. Cowell's Table X. for the apparent coefficients of the *sine* and *cosine* of the various arguments considered, as the actual values corresponding to the adopted date.

The criticisms I have to offer deal with the proper interpretation to be put on the results which have been deduced from the

analysis of the observations, and to the consequent conclusion which should be drawn. In cases Mr. Cowell has failed to do justice to his own results, and has drawn his conclusions in a manner open to improvement and to extension, whilst in others he appears to have misinterpreted their real meaning, and in consequence to have failed to draw the proper conclusion. But the results obtained and the conclusions drawn are far too important to permit this being done without comment; for, correctly interpreted, the results obtained by Mr. Cowell in this investigation afford most valuable information concerning the most difficult parts of the lunar theory. It is also desirable to show exactly how far the results deduced by Mr. Cowell are in accord with the observations, and to what extent and in what manner they may require supplementing, before they adequately represent the observed errors of the tables.

I have already drawn Mr. Cowell's attention to the fact that the coefficients yielded by his method of investigation are not the true coefficients of the argument being investigated, but "apparent" coefficients involving fractional portions of the coefficients of other arguments besides that being specially considered, and that unless precautions were taken to eliminate these disturbing elements, the results obtained by means of these apparent coefficients might prove most misleading (*Monthly Notices*, 1904 May, pp. 604–5).

Mr. Cowell does not seem, however, to have fully realised the necessity of taking these precautions, and has thought it sufficient when investigating the coefficient of the term with the arguments

$$[g \cdot g']$$

to take into account the influence exerted on the values obtained by errors in the coefficients of the associated terms with the arguments

$$[g \cdot g'] \pm \mathrm{D}$$

excepting in a few instances involving terms due to the disturbing action of the planets.

But this is not sufficient. If

$$\frac{1}{n} \Sigma_1^n \sin i\mathrm{D} = s_i \qquad \frac{1}{n} \Sigma_1^n \cos i\mathrm{D} = c_i$$

represent the mean value of the sine and cosine of the argument $i\mathrm{D}$ for the observations involved, it has been found from a discussion of the entire series of 150 years' observations, that with a considerable degree of approximation it may be taken that

$$s_1 = +0{\cdot}061 \quad s_2 = -0{\cdot}050 \quad s_3 = +0{\cdot}025$$
$$c_1 = -0{\cdot}525 \quad c_2 = -0{\cdot}111 \quad c_3 = -0{\cdot}175$$

so that terms depending on the associated arguments

$$\sin\{[g\,.\,g']\pm 2D\} \quad \sin\{[g\,g']\pm 3D\}$$
$$\cos\{[g\,g']\pm D\} \quad \cos\{[g\,.\,g']\pm 2D\} \quad \cos\{[g\,g']\pm 3D\}$$

will also cause small systematic errors in the apparent values of the coefficients of the argument

$$[g\,.\,g']$$

in addition to the larger discordances arising from the terms

$$\sin\{[g\,.\,g']\pm D\}$$

which alone have been taken into account by Mr. Cowell.

But a more important case is the mutual systematic interference of the coefficients of the mean anomalies of the Moon and Sun. Let the terms depending on these arguments be denoted by

$$A' \sin g + A'' \cos g + M' \sin g' + M'' \cos g'$$

and let the apparent coefficients of these arguments obtained by Mr. Cowell's method be denoted by

$$A_s \;\; A_c \;\; M_s \;\; M_c$$

Then, as

$$g = g' - (\omega - \omega') + D \qquad g' = g + (\omega - \omega') - D$$

and denoting the mean value of the cosine of D by c_1, the values actually obtained for the apparent coefficients, by Mr. Cowell's method, will be

$$A_s = A' \; - c_1\{M' \cos(\omega - \omega') - M'' \sin(\omega - \omega')\}$$
$$A_c = A'' - c_1\{M' \sin(\omega - \omega') + M'' \cos(\omega - \omega')\}$$

$$M_s = M' \; - c_1\{A' \cos(\omega - \omega') + A'' \sin(\omega - \omega')\}$$
$$M_c = M'' + c_1\{A' \sin(\omega - \omega') - A'' \cos(\omega - \omega')\}$$

As the argument

$$\omega - \omega' = \varpi - \varpi'$$

has a period of nine years, it is obvious that there will be set up nine-year inequalities in the apparent values of the coefficients of both g and g', which may be very sensible in the mean values deduced from the results of twelve to twenty-five years' observations, though usually they will be small in the case of values deduced from series of observations extending over forty to fifty years.

It is obvious that similar but smaller inequalities will be set up by the coefficients of the term

$$g' \pm iD$$

and similar inequalities of only half the period by the coefficients of the arguments

$$g-2g'\pm iD.$$

When dealing with the mean values of coefficients derived from series of observations extending over fifty years, these inequalities will have little influence on the results obtained, and under these conditions they may be ignored, as has been done by Mr. Cowell.

But there is a further development to be considered.

Let

$$Z'\sin(g+\zeta)+Z''\cos(g+\zeta)$$
$$Y'\sin(g'+\zeta')+Y''\cos(g'+\zeta')$$

denote pairs of terms whose arguments only differ from g and g' by the arguments of long-period ζ and ζ' respectively. Then the values which will be deduced from observation will be

$$\begin{aligned}
A_s &= A' + Z'\cos\zeta - c_1\{M'\cos(\omega-\omega')+Y'\cos(\omega-\omega'+\zeta')\} \\
&\qquad - Z''\sin\zeta + c_1\{M''\sin(\omega-\omega')+Y''\sin(\omega-\omega'+\zeta')\} \\
A_c &= A'' + Z'\sin\zeta - c_1\{M'\sin(\omega-\omega')+Y'\sin(\omega-\omega'+\zeta')\} \\
&\qquad + Z''\cos\zeta - c_1\{M''\cos(\omega-\omega')-Y''\cos(\omega-\omega'+\zeta')\} \\
M_s &= M' + Y'\cos\zeta' - c_1\{A'\cos(\omega-\omega')+Z'\cos(\omega-\omega'+\zeta)\} \\
&\qquad - Y''\sin\zeta' - c_1\{A''\sin(\omega-\omega')-Z''\sin(\omega-\omega'+\zeta)\} \\
M_c &= M'' + Y'\sin\zeta' + c_1\{A'\sin(\omega-\omega')+Z'\sin(\omega-\omega'+\zeta)\} \\
&\qquad + Y''\cos\zeta' - c_1\{A''\cos(\omega-\omega')+Z''\cos(\omega-\omega'+\zeta)\}
\end{aligned}$$

Now reckoning in years Y from the epoch Y_0, when the argument was zero, we may write

$$\omega-\omega' = \varpi-\varpi' = +40^{\circ}{\cdot}67\,(Y-Y_0)$$

so that the annual increment of the argument is rather less than 41°, and the period rather less than nine years. Hence, if the arguments denoted by ζ and ζ' be supposed to have annual increments differing from that of $(\omega-\omega')$ by not more than 5°, they will give rise to apparent inequalities in the values of the coefficients A_s, A_c and M_s, M_c of more than seventy years' period, and these will not disappear from the mean results derived from fifty years' observation.

These Mr. Cowell has failed to take into account.

There exist a considerable number of terms of this character in the expression for the Moon's longitude; as, for instance, the term to which Mr. Cowell assigns the value

$$-0''{\cdot}70\sin(2D-g+3V-3E)$$

which has an argument whose annual increment differs from that of g by

$$2\varpi+3V-5E=36^{\circ}{\cdot}92$$

and will give rise to apparent inequalities of ninety-seven years' period in the values found for the coefficient of g'. Another is the term to which M. Radau assigns the value

$$+0''{\cdot}181 \sin\{3V-4E+88^{\circ}\}$$

which will give rise to an inequality of similar period in the apparent value of the coefficient of the mean anomaly g, which will not disappear from the mean of fifty years' observations.

As the long-period inequalities in the Moon's mean longitude must give rise to subsidiary terms of the form

$$Z'' \cos(g+\zeta)$$

they must all produce inequalities of about nine years' period in the apparent value of the coefficients of g', and so systematically affect the values derived, from observation by Mr. Cowell, for the coefficients of such arguments as

$$g' \pm (\omega-\omega')$$

and these in turn affect the value he assigns to the real coefficient of the arguments

$$D \pm g'(\omega-\omega')$$

In the same manner inequalities of long period in the apparent coefficient of g' will give rise to inequalities of about nine years' period in the coefficients of g derived from observation, and so systematically affect the values found by Mr. Cowell for the coefficients of the arguments of the form

$$g \pm (\omega-\omega')$$
$$D \pm g \pm (\omega-\omega')$$

Mr. Cowell has not investigated the variations in the values of the coefficients of the argument g' derived from the observations, though they are of considerable magnitude and indicate the existence of inequalities of some importance. Therefore to supply the omission I take from my own results the following values of the coefficients of the expressions

$$M\ = +\Delta M_s + Q'_s \cos(\omega-\omega')+Q''_s \sin(\omega-\omega')$$
$$M_c = +\Delta M_c + Q'_c \sin(\omega-\omega')+Q''_c \cos(\omega-\omega')$$

derived from yearly values of the coefficients of the Sun's mean anomaly obtained through the solution of a system of simultaneous equations which serve to eliminate these fictitious inequalities. The value for each is derived from a group of

eighteen years' observations, so that the values of ΔM_s and ΔM_c are independent of the effects of the errors in Hansen's tabular coefficients, and represent the effects of omitted terms of very long period.

The values for these coefficients are

	ΔM_s	Q'_s	Q''_s	ΔM_c	Q'_c	Q''_c
1891	$= -$ ″·60	$= +$ ″·61	$= +$ ″·12	$= -$ ″·41	$= -$ ″·47	$= +$ ″·03
82	$= -$ ·83	$= +$ ·75	$= +$ ·30	$= -$ ·42	$= -$ ·69	$= +$ ·28
73	$= -$ ·65	$= +$ ·83	$= +$ ·29	$= -$ ·35	$= -$ ·58	$= +$ ·08
64	$= -$ ·44	$= +$ ·66	$= +$ ·19	$= -$ ·49	$= -$ ·45	$= +$ ·30
55	$= -$ ·28	$= +$ ·53	$= +$ ·03	$= -$ ·32	$= -$ ·33	$= +$ ·53
46	$= +$ ·03	$= +$ ·97	$= -$ ·17	$= +$ ·00	$= -$ ·47	$= +$ ·27
37	$= -$ ·14	$= +$ ·95	$= -$ ·20	$= +$ ·04	$= -$ 1·28	$= +$ ·84
28	$= -$ 1·04	$= +$ ·98	$= -$ ·15	$= +$ ·30	$= -$ 1·66	$= +$ ·49
19	$= -$ ·72	$= +$ 1·18	$= -$ ·31	$= +$ ·14	$= -$ 1·85	$= -$ ·34
10	$= +$ ·30	$= +$ ·82	$= -$ ·52	$= -$ ·29	$= -$ ·87	$= +$ ·55
1801	$= +$ ·51	$= -$ ·04	$= -$ ·32	$= -$ ·50	$= -$ ·03	$= +$ ·71
1792	$= -$ ·44	$= -$ ·40	$= -$ ·51	$= -$ ·50	$= +$ ·15	$= +$ ·74
83	$= -$ ·94	$= +$ ·06	$= +$ ·11	$= -$ ·49	$= +$ ·43	$= +$ 1·02
74	$= -$ ·36	$= +$ ·02	$= +$ ·41	$= -$ 1·24	$= -$ ·37	$= +$ ·02
65	$= -$ ·31	$= +$ ·91	$= +$ ·37	$= -$ 1·05	$= -$ 1·23	$= -$ ·24
1759	$= -$ ·22	$= +$ 1·01	$= +$ ·42	$= -$ ·29	$= -$ 1·65	$= -$ ·09

These values show clearly the existence of inequalities of long period in the coefficients of g' which must give rise to apparent fictitious inequalities of about nine years' period in the values found by Mr. Cowell for the coefficients of the Moon's mean anomaly, whilst the large variations in the Q coefficients show the existence of important inequalities with arguments of similar period to that of the argument $(\omega - \omega')$, and these will give rise to fictitious inequalities of very long period in the values which Mr. Cowell has deduced for the coefficients of g, which will not disappear from the mean of fifty years' observation.

Similar terms, though of smaller dimensions, will arise depending on the argument

$$2\omega - 2\omega'$$

and must be taken into account before the true value of the *elliptic inequality* can be deduced by the method adopted by Mr. Cowell.

The motion of the lunar perigee will give rise to a further set of corrections which must be taken into account before the true value can be obtained of the corrections to the coefficients of the perturbations.

Writing for brevity

$$p = \omega - \omega' = \varpi - \varpi'$$

it can be shown that the terms

$$X' \sin x + X'' \cos x + C_1 \sin \{x - [ig' - jp]\} + C_2 \sin \{x - [ig' + jp]\}$$
$$+ C_3 \sin \{x + [ig' - jp]\} + C_4 \sin \{x + [ig' + jp]\}$$

will yield for the apparent coefficients of the argument x the values

$$X_s = X' - \frac{j}{i}\{m_1(C_1 - C_2 + C_3 - C_4) + m_2(C_1 + C_2 + C_3 + C_4)\} \cos j(p)$$

$$X_c = X'' - \frac{j}{i}\{m_1(C_1 + C_2 - C_3 - C_4) + m_2(C_1 - C_2 - C_3 + C_4)\} \sin j(p)$$

where approximately

$$m_1 = +0{\cdot}11 \qquad m_2 = +0{\cdot}01$$

The second of these coefficients is too small for the terms depending on it to be sensible, except for errors of very large dimensions, such as some of those in the coefficients of the perturbations adopted in Airy's lunar tables.

It was on account of the necessity of eliminating these fictitious inequalities and avoiding the many complex consequent corrections arising from unknown as well as known errors in the tabular values required to obtain the true values of the coefficients, that in my own investigations the values of the different coefficients were deduced in the form

$$C_s = C_i + \Sigma_1^i \{a_i' A_i' + a_i'' A_i'' + m_i' M_i' + m_i'' M_i'' + d_i' D_i'$$
$$+ d_i'' D_i'' + \ldots\}$$

The numerical factors $a_i' \ldots d_i'$ in these expressions range generally between $\pm 0{\cdot}25$, although d_1 is much larger, and the notation is

$$A_i' \sin ig + A_i'' \cos ig$$

By treating these expressions as a set of simultaneous equations, the values of all the subsidiary coefficients

$$A'A'' \ldots D_i'D_i''$$

were eliminated by the value for that year. In this manner not only are more accurate values obtained for the coefficient, but all these subsidiary terms and associated corrections are removed with the corresponding principal term.

(2) The first step in the investigations of the origin of the observed errors of the lunar tables is to consider the bearing of the results obtained from theory by M. Radau (*Annales de*

l'Observatoire de Paris, Mémoires, tome xxi., B. 1, 1895). Adopting the Delaunay-Hill method, M. Radau has calculated from theory the values of the perturbations produced by the disturbing action of the planets in the expression for the longitude of the Moon. Assuming that the method employed yields the complete value of the coefficients of the terms arising from the disturbing action of the planets, a critical examination will show that the care and completeness with which the calculations have been made, in the great majority of cases must ensure the results obtained representing the true theoretical coefficient of the terms within a few thousandths of a second of arc. This being so, to take into account the complete theoretical value of the perturbations produced by the planets it should suffice to supplement the tables by the small number of terms found to possess sensible coefficients by the calculations of M. Radau.

Adopting M. Radau's results as expressing the complete effect of the disturbing action of the planets, by omitting the terms reflecting the secondary effects of the terms of very long period, the terms required to express the complete perturbations in the Moon's longitude due to the action of the planets may be divided into two classes—the terms whose coefficients exceed a quarter of a second of arc and the terms whose coefficients are greater than a tenth of a second of arc but less than one quarter of a second; the terms with still smaller coefficients being disregarded as insensible.

These two classes are :—

	Argument.	Coefficient according to M. Radau.	Coefficient adopted by Hansen.
	°	″	″
Class I.	$\sin\{2D - g + 2E - 2J\}$	−0.881	
	$\sin\{V - E'\}$	−0.860	−1.10
	$\sin\{2D - g + 3V - 3E\}$	−0.681	...
	$\sin\{E - J\}$	+0.646	+ ·74
	$\sin\{E - 2M - 49\}$	+0.422	+ ·32
	$\sin\{2V - 3E + 85\}$	−0.348	
	$\sin\{2D - g + 2E - 3J + 7\}$	+0.316	
	$\sin\{2V - 2E\}$	+0.283	+ ·43
Class II.	$\sin\{2E - 2M\}$	+0.228	+ ·24
	$\sin\{2D - g - E + J\}$	−0.220	
	$\sin\{2D - 2g + 2E - 2J\}$	−0.206	
	$\sin\{2E - 2J\}$	−0.196	− ·24
	$\sin\{2D - 2g + 2E - 3J\}$	+0.194	
	$\sin\{2D - g + 2V - 2E\}$	+0.192	
	$\sin\{3V - 4E + 88\}$	−0.181	
	$\sin\{2D - E + J\}$	−0.175	
	$\sin\{E - 2J + 298\}$	+0.172	

	Argument.	Coefficient according to M. Radau.	Coefficient adopted by Hansen.
		″	″
Class II.	sin {2D − g − 2V + 2E °}	−0.172	
	sin { g − 2E + 2J }	−0.167	
	sin {2D − 2V + 2E }	−0.148	
	sin {2D − g − V + E }	+0.143	
	sin {2D − g − 20V + 21E + 272}	+0.143	
	sin { J + 99}	+0.139	
	sin { g − 3V + 3E }	−0.138	
	sin { 2E − 4M + 293}	+0.112	
	sin { g − 26V + 29E + 121}	+0.110	
	sin {2D − g + E − J }	+0.101	
	sin {2D − V + E }	+0.105	

Mr. Cowell does not clearly define his position with respect to these theoretical results obtained by M. Radau. In his earlier papers he seems to have regarded them as accurately representing the complete value of the terms, so that, to eliminate the effects of the disturbing action of the planets to the order of approximation he had adopted, it sufficed to supplement the lunar tables by the addition of the terms

$$\begin{aligned}
&-0''.881 \sin\{2D-g+2E-2J\} \\
&-0.681 \sin\{2D-g+3V-3E\} \\
&-0.348 \sin\{2V-3E+85^\circ\} \\
&+0.316 \sin\{2D-g+2E-3J+7^\circ\}
\end{aligned}$$

the other terms being neglected as having coefficients under 0″·30 in magnitude, the limit adopted for his approximation. This would be a perfectly legitimate position to adopt.

But in his subsequent papers Mr. Cowell appears to have departed from this position, and to assume that, even though the tabular places have been corrected by the application of the values for these terms deduced from theory by M. Radau, yet there may still remain outstanding corrections depending on these arguments which have to be determined from the observed errors of the corrected tables. This corresponds to the assumption that M. Radau's theoretical values may need supplementing. Thus, in the *Monthly Notices* for 1904 June, he deduces the correction

$$\begin{array}{ll}
-0''.34 \sin\{V-E\} & -0''.02 \cos\{V-E\} \\
+0.10 \sin\{2V-2E\} & -0.01 \cos\{2V-2E\} \\
+0.01 \sin\{E-J\} & -0.13 \cos\{E-J\} \\
+0.29 \sin\{2V-3E+85^\circ\} & +0.00 \cos\{2V-3E+85\} \\
-0.33 \sin\{E-2M-49\} & -0.06 \cos\{E-2M-49\} \\
+0.01 \sin\{2E-4M+272\} & -0.05 \cos\{2E-4M+272\}
\end{array}$$

Originally this may have been done to show that the values deduced from theory by M. Radau agreed with the observed values; and in this sense Mr. Cowell appears to have regarded the results deduced by him from the observations, taking them as showing that Hansen's values when corrected yielded the values

$$\{-1''\!\cdot\!10-0''\!\cdot\!34=-0''\!\cdot\!76\}\ \sin\{\ V-\ E\qquad\}$$
$$\{+0\cdot43-0\cdot10=+\ \cdot33\}\ \sin\{2V-2E\qquad\}$$
$$\{+0\cdot00-0\cdot29=-\ \cdot29\}\ \sin\{2V-3E+85°\}$$

which were in far better agreement with the theoretical values deduced by M. Radau than with those adopted by Hansen. At the same time his results indicated that Hansen's value of the term with the argument (E—J) agreed far better with the observations than that deduced by M. Radau, and that the value indicated by the observations for the term with the argument (E—2M—49°) agreed with neither Hansen nor Radau.

Finally the results given in the *Monthly Notices* for 1904 December appear to indicate that Mr. Cowell had found it desirable to throw over the values deduced from theory by M. Radau, as in his adopted values he changes very materially the coefficients yielded by theory.

Thus he makes the changes

$-0''\!\cdot\!881\ \sin\{2D-g+2E-2J\}$	coefficient increased to		$-1''\!\cdot\!10$
$+0\cdot316\ \sin\{2D-g+2E-3J+7°\}$	„	„	$+0\cdot40$
$-0\cdot167\ \sin\{g-2E+2J\}$	„	„	$-0\cdot30$
$+0\cdot101\ \sin\{2D-g+E-J\}$	„	„	$+0\cdot20$
$-0'\!\cdot\!860\ \sin\{V-E\}$	coefficient reduced to		$-0''\!\cdot\!80$
$+0\cdot192\ \sin\{2D-g+2V-2E\}$	„	„	$+0\cdot00$
$-0\cdot181\ \sin\{3V-4E+88°\}$	„	„	$-0\cdot10$
$-0\cdot172\ \sin\{2D-g+2V-2E\}$	„	„	$-0\cdot10$

These are very material changes in the values for the coefficients of these terms, and the modified values adopted by Mr. Cowell as indicated by the observations are quite inconsistent with the results deduced from theory by M. Radau.

Mr. Cowell appears to regard these alterations he has made as simply changes from one theoretical value to another just as permissible, and merely as indications that the value deduced from theory by M. Radau is more accurate than that similarly deduced by Hansen and employed in his tables, or *vice versa.* But it means much more. For the value for the coefficients of these terms employed by Hansen consists merely of the principal term arising from the indirect action of the planet on the Moon

through the perturbations it produces in the motion of the Earth. It forms a rough approximation to the true value, and cannot be compared with the more accurate and complete result deduced by M. Radau, which corresponds with the result which would have been obtained by Hansen had he thought it necessary to carry his calculations to the same degree of approximation.

But the changes proposed by Mr. Cowell are entirely inconsistent with M. Radau's values, which are, speaking generally, accurate within a few thousandths of a second of arc, and cannot possibly be changed by 20 or 30 per cent. of their values on any permissible assumption except that the method of calculation employed by M. Radau fails to give the complete values of the terms. Thus it is possible that a still more detailed calculation of the value of the coefficient of the Jovian evection by the same method as employed by M. Radau might yield a slightly corrected value; but it would be one lying between the limits of $0''\cdot 90$ and $0''\cdot 88$; and no such revision or elaboration of the details of the calculation could raise the value to over $1''\cdot 00$, much less to $1''\cdot 10$, the value adopted by Mr. Cowell. Such a modification is only possible by supposing that the Delaunay-Hill method adopted by M. Radau fails to give the complete value of the coefficients of these terms owing to the omission of a class of important factors necessary to the complete value of the coefficients.

If the comparison of the observed and tabular places of the Moon had shown that the values, calculated from theory, of the coefficients of the more important terms arising from the disturbing action of the planets were in complete accord with those indicated by observation, and that no further correction to the adopted theoretical values were left outstanding, then it would have sufficed to have taken into account such of the terms which the theoretical calculations indicated were large enough to be sensible, and to have neglected all the others as insensible.

But as the observations show that these values deduced from theory are not in accord with the observations, but need supplementing in the manner indicated by Mr. Cowell (*Monthly Notices*, 1904 December, Table X.), thus indicating that the method adopted for calculating these terms cannot yield their complete value, then, in investigating the origin of the errors of the lunar tables, it is essential to take into consideration, not only the possible errors in the values of the larger coefficients of the term adopted from theory, but also the possible errors in the terms having small coefficients according to the defective theory.

In this respect Mr. Cowell's investigation fails, for he has confined his attention to such terms as have coefficients of over a tenth of a second (with one exception), and has omitted to pay any attention to the associated terms of similar origin whose coefficients are small according to M. Radau. Thus Mr. Cowell deduces corrections to M. Radau's value of the term

$$-0''\cdot 681 \sin\{2D-g+3V-3E\}$$

but ignores altogether the companion term

$$-0''\cdot019 \sin\{2D-g+4E-4M\}$$

though the period of the two terms is so close that without special care they cannot be separated by a discussion of the observations. But if the coefficient of the former is held to be incomplete, so must the coefficient of the latter, and therefore corrections to both must be deduced from the observations before either can be deemed accurate.

Similarly with the two terms to which M. Radau assigns the values

$$-0''\cdot181 \sin\{3V-4E+88^\circ\}$$

and

$$+0''\cdot055 \sin\{3E-4M+328^\circ\}$$

Mr. Cowell considers the first and deduces a correction, yet ignores the second, though the periods of the two are so very similar that for years their coefficients cannot be separately deduced from the observations.

(3) These essential preliminary considerations having been dealt with, it remains to consider the actual corrections to the lunar tables deduced by Mr. Cowell from his discussion of the observations.

Mr. Cowell's results may be divided into

I. His corrections to the secular terms and empirical inequalities of very long period.

II. The values deduced by him for the coefficients of the inequalities arising from the disturbing action of the planets.

III. The corrections he deduces for the tabular coefficients of the perturbation due to the direct action of the Sun.

These will be considered in order.

(4) Mr. Cowell's value for the corrections to Hansen's secular terms, and for the semi-secular terms of very long period which should be included in the tables, appears to have been originally

$$\begin{aligned}-5''\cdot44-29''\cdot17(T-1800\cdot0)-3''\cdot76(T-1800\cdot0)^2 \\ +17''\cdot86 \sin\{0^\circ\cdot99[Y-1850\cdot50]+146^\circ\cdot9\} \\ +15''\cdot34 \sin\{18V-16E-a+35^\circ\cdot3\}\end{aligned}$$

to which would have to be added the corrections necessary to reduce Hansen's tabular value for the two long *Venus* terms to their values according to the latest published theoretical calculation, which give

$$\begin{aligned}+14''\cdot40 \sin\{18V-16E-a+30^\circ\cdot6\} \\ +0''\cdot27 \sin\{8V-13E+228^\circ\cdot0\}\end{aligned}$$

To these Mr. Cowell adds the two smaller empirical terms of long period

$$+2''\cdot35 \sin \{5^\circ\cdot44[Y-1850\cdot50]+55^\circ\}$$
$$+\ \cdot73 \sin \{8\cdot60[Y-1850\cdot50]+15\}$$

This may be called Cowell's Solution I. It corresponds to a value of the secular acceleration in the Moon's mean longitude of

$$+8''\cdot42(T-1800\cdot0)^2$$

At the same time Mr. Cowell points out that the above empirical term of 363 years' period can be replaced by the combination

$$+5''\cdot20-3''\cdot00(T-1800\cdot0)-4''\cdot40(T-1800\cdot0)^2$$
$$+12''\cdot16 \sin \{1^\circ\cdot10[Y-1850\cdot5]+152^\circ\cdot1\}$$

But this corresponds to a reduction of the secular acceleration of the mean motion to

$$+4''\cdot02(T-1800\cdot0)^2$$

or to only two thirds of the minimum theoretical value, and Mr. Cowell does not seem to refer further to this modification in his paper. It was distinguished as Cowell Solution II.* This solution assumes so great a reduction of the secular acceleration that it does not require further consideration.

Yet in his last paper in the *Monthly Notices* for 1905 January, p. 273, Mr. Cowell reverts to this alternative system of correction, but halves the proposed correction to the secular terms, adopting

$$+2''\cdot60-1''\cdot50(T-1800\cdot0)-2''\cdot20(T-1800\cdot0)^2$$

* I do not understand Mr. Cowell's remark in connection with this solution (*Monthly Notices*, 1904 November, pp. 34–5) where he says: "The above formula has been formed on the assumption that one, and only one, empirical term of very long period is to be introduced, and also the secular acceleration is not to be altered. With these limitations I believe the solution is unique; that is to say, it only admits of variations proportional to the errors of observation, and no totally different solution can be found." It appears to me to be a mere truism. The observed errors of the tables form a fixed simple curve. If no changes are to be made in the coefficients of the arguments derived from theory—for if so they would then become additional empirical terms which are barred—no change is to be made in the secular acceleration, and no change in the mean motion can represent a curve; all that is left to vary so as to represent the observed curve is the solitary empirical term, and of course there can be but one value of such a term which can represent the fixed curve of observation. Obviously no totally different value can do so. If it were meant that only one new empirical *argument* of long period was to be introduced, but that any desired changes might be introduced into the coefficients of any of the tabular terms of long period, then Mr. Cowell's solution being "unique" would be something of great importance. But it would not be a fact, for under these conditions by merely varying the coefficient of Hansen's direct *Venus* term it is possible to find a dozen empirical terms with periods from 250 to 400 years which will represent the observations between 1900 and 1750 quite as closely as Mr. Cowell's.

corresponding to the value of the secular acceleration of the mean motion of

$$+6''\cdot22(T-1800\cdot0)^2$$

which is very close to its theoretical value. Mr. Cowell does not state whether this halving of the secular terms is to be accompanied by a proportionate change in the empirical term of long period, which would bring it to the value

$$+15''\cdot0 \sin\{1^\circ\cdot05[Y-1850\cdot50]+351^\circ\cdot4\}$$

a term of some 343 years' period. Judging from Mr. Cowell's remark (*Monthly Notices*, 1904 November, p. 35), that the ancient eclipses seem to "point to a negative correction to the secular acceleration of about 2'', my conclusion is that if a single long-period empirical term alone exists, its period should be about 350 years." It would seem that this is the term he intends.

If so, his finally adopted correction, Cowell No. III., becomes Hansen

$$\begin{aligned}
&-2''\cdot84-30''\cdot67(T-1800\cdot0)\\
&\quad-\ 5\cdot96(T-1800\cdot0)^2\\
&\quad+14\cdot40\sin\{18V-16E-g+30^\circ\cdot6\}-15''\cdot34\sin\{18V-16E-g+35^\circ\cdot3\}\\
&\quad+\ 0\cdot27\sin\{8V-13E+228^\circ\cdot0\}-21''\cdot47\sin\{8V-13E+274^\circ\cdot4\}\\
&\quad+15\cdot00\sin\{1^\circ\cdot05[Y-1850\cdot50]+351^\circ\cdot4\}\\
&\quad+\ 2\cdot35\sin\{5^\circ\cdot44[Y-1850\cdot50]+55^\circ\}\\
&\quad+\ \cdot73\sin\{8^\circ\cdot60[Y-1850\cdot50]+15^\circ\}
\end{aligned}$$

If however the empirical term of Mr. Cowell's alternative solution is to be left unaltered when the secular corrections are halved, the modified expression will form Cowell Solution IV.

It remains to ascertain how far these systems of corrections deduced by Mr. Cowell are in accord with the observed errors of the tables.

For the purpose of comparison a set of standard tabular errors were formed as follows. The tabular error yielded by each observation was equated to the expression

$$L+M_s\sin g'+M_c\cos g'+A_s\sin g+A_c\cos g+P_s\sin D+P_c\cos D+V_s\sin 2D+V_c\cos 2D+\delta S$$

and the mean of all the observations for the year was taken. The small outstanding corrections depending on the *sine* and *cosine* of the *annual equation*, *mean anomaly*, *parallactic inequality*, and *variation*, together with the necessary correction

for semi-diameter, were then eliminated by their values determined from the observations of that year. This yielded the mean error for the year, sensibly free from all tabular errors except those of moderately long period. To eliminate these there was applied the system of correction for these terms deduced by Mr. Cowell from the observations and given in Table X. in the *Monthly Notices* for 1904 December. This system was taken as being

$$
\begin{array}{ll}
-0''.59 \sin & \{\omega - \omega'\} \\
+0.09 \sin & \{2\omega - 2\omega'\} \\
+0.16 \sin & \{2\omega\} \\
-1.15 \sin & \{\Omega\} \\
+0.30 \sin & \{V - E\} \\
-0.13 \sin & \{2V - 2E\} \\
-0.30 \sin & \{2V - 3E + 85^\circ\} \\
+0.08 \sin & \{E - 2M - 49^\circ\} \\
-0.04 \sin & \{E - J\} \\
+0.20 \sin & \{E - 2J + 298^\circ\} \\
+0.20 \sin & \{\varpi - 2J\}
\end{array}
$$

The yearly values thus corrected were divided into nine-year groups, and the mean of each group taken as the standard tabular error for the middle of the group. Such errors were determined at different five-year epochs.

From the discordance between the observed and the calculated errors of Hansen's tables between the years 1862–1878 it has been shown that the outstanding errors of the tables are in the great majority of cases much below $\pm 2''\cdot 0$, and the probable error of an observation, apart from the errors of the tables themselves, is less than $\pm 1''\cdot 0$ (*Memoirs R.A.S.* xlviii. p. 392). As the mean error for each year generally depends on a hundred observations, the accidental error of the mean for the year should be less than a sixth of a second of arc, and the discordance between the observed and the properly corrected tabular places should rarely exceed $\pm 0''\cdot 30$ in the mean for the year. The mean error outstanding in a group of nine years should rarely exceed $\pm 0''\cdot 05$. Hence any discordance between the calculated and the observed errors of the tables exceeding $\pm 0''\cdot 25$ in the mean of a nine-year group must be regarded as due to imperfections in the adopted system of corrections, and should such discordances exceed $\pm 0''\cdot 50$ the adopted system must be regarded as a failure.

The earlier observations are not so accurate as those made with the Greenwich Transit Circle, but still those made between 1850–1817 with the Troughton Transit and Mural Circle, when properly corrected, are not much inferior to those made since 1851 with the Transit Circle. Probably the above values should be

increased by about a third, so that when properly corrected the tables should not show discordances between observation and calculation exceeding $\pm 0''\cdot 40$ in the mean of any year, or $\pm 0''\cdot 20$ in the mean of a nine-year group. Hence during this period the occurrence of discordances exceeding $\pm 0''\cdot 60$ between the observed and calculated mean error for a nine-year group must be held as showing the system of correction adopted to break down. The still earlier observations made with the Bird Transit and Brass Quadrant are even more uncertain, and it may be taken that the observed discordance between observation and calculation should not reach $\pm 0''\cdot 60$, and such discordances as $\pm 1''\cdot 00$ be held as proof of failure.

The earlier observations prior to 1750 come into a different category. Yet judging from the discordances shown by separate observations, and allowing for the much smaller number of observations going to form a nine-year group, the discordance between observation and a proper system of tabular corrections should not exceed $\pm 1''\cdot 00$ between 1750 and 1710, nor exceed $\pm 2''\cdot 00$ between 1700 and 1660, but might rise to $\pm 4''\cdot 00$ for the epochs prior to 1660.

Hence it may be laid down that no system of corrections to the tables can be regarded as satisfactory if the discordance between the observed and calculated errors of the tables exceed the following amounts :—

Period	1900–1851	Maximum discordance	$= \pm\ ''\cdot 50$
	1850–1820		$= \pm\ \cdot 75$
	1820–1750		$= \pm 1\cdot 00$
	1750–1700		$= \pm 1\cdot 50$
	1700–1660		$= \pm 2\cdot 50$
	1660–1640		$= \pm 4\cdot 00$
	1640–1620		$= \pm 6\cdot 00$

whilst a proper system of corrections should agree with the observed error to within two-thirds of these values. It will be seen that the possibility of systematic error has been magnified as much as possible in forming the preceding estimate so as to form a criterion as favourable as possible to the system of adopted corrections.

Then the comparison of the three systems of corrections deduced by Mr. Cowell, and distinguished as "Cowell Solution I.," "Cowell Solution III.," and "Cowell Solution IV." (omitting No. II. owing to the impossible value of the secular acceleration), with the system of standard errors obtained as described above, yields the following values for the outstanding mean error of the tables at equidistant five-year epochs from 1900 to 1630. (The observed error for the epoch 1900 is derived from a group of only five years, as the observed errors for the years 1903 and 1904 were not available.)

	Observed Tabular Error.	(Observed—Computed) Tabular Error. Cowell Solution I.	Cowell Solution III.	Cowell Solution IV.	Cowell Solution IV.*
	″	″	″	″	″
1900	+25·61	+ 1·17	− ·23	− ·56	+ ·94
1895	+20·57	− 1·29	− 2·66	− 3·23	− 1·73
90	+17·48	− ·74	− 2·03	− 2·79	− 1·29
85	+14·99	− ·26	− 1·50	− 2·47	− ·97
80	+11·99	+ ·33	− ·83	− 2·01	− ·51
75	+ 8·54	+ ·58	− ·53	− 1·88	− ·38
70	+ 5·51	+ 1·64	+ ·57	− ·97	+ ·53
65	+ 1·70	+ 1·04	+ ·04	− 1·65	− ·15
60	− 1·54	+ ·33	− ·62	− 2·47	− ·97
55	− 2·09	+ ·88	− ·01	− 2·00	− ·50
50	− ·83	+ 2·27	+ 1·44	− ·66	+ ·84
45	− ·26	+ 1·92	+ 1·15	− 1·10	+ ·39
40	+ ·10	+ 1·17	+ ·47	− 1·88	− ·38
35	+ 1·55	+ 1·51	+ ·96	− 1·49	+ ·01
30	+ 1·19	+ 1·97	+ ·18	− 1·36	+ ·14
25	+ 1·08	+ ·52	− ·02	− 2·64	− 1·14
20	+ 2·65	+ 2·72	+ 1·74	− ·95	+ ·55
15	+ 3·23	+ 3·98	+ 2·57	− ·18	+ 1·32
10	+ 1·94	+ 1·79	+ 1·43	− 1·35	+ ·15
05	+ 2·23	+ 2·17	+ 1·87	− ·94	+ ·56
1800	+ 2·82	+ 2·82	+ 2·60	− ·24	+ 1·26
1795	+ 1·91	+ 2·24	+ 2·02	− ·86	+ ·64
90	+ 1·16	+ 1·57	+ 1·44	− 1·43	+ ·07
85	+ 1·68	+ 2·33	+ 2·27	− ·57	+ ·93
80	+ 1·44	+ 1·72	+ 1·71	− 1·01	+ ·49
75	+ 1·79	+ 1·64	+ 1·69	− 1·10	+ ·40
70	+ 2·92	+ 1·67	+ 1·80	− ·94	+ ·56
65	+ 2·68	+ ·97	+ 1·17	− 1·51	− ·01
60	+ 1·77	− ·24	− ·04	− 2·69	− 1·19
55	+ ·25	+ ·97	+ ·37	− 2·18	− ·68
50	+ ·31	+ ·77	+ ·28	− 1·35	+ ·15
45	− 3·05	+ ·41	+ ·81	− 1·54	− ·04
40	− 5·08	+ 1·58	+ 2·04	− ·62	+ ·88
35	− 5·62	+ 4·35	+ 4·87	+ 2·73	+ 4·23
30	− 6·43	+ 6·12	+ 6·70	+ 4·71	+ 6·21
25	− 8·04	+ 6·64	+ 7·28	+ 5·43	+ 6·93
20	− 9·95	+ 6·14	+ 6·84	+ 5·16	+ 6·66
15	−10·45	+ 6·88	+ 7·53	+ 6·10	+ 7·60

	Observed Tabular Error.	(Observed—Computed) Tabular Error. Cowell Solution I.	Cowell Solution III.	Cowell Solution IV.	Cowell Solution IV.*
	″	″	″	″	″
1710	−13·80	+ 4·67	+ 5·49	+ 4·14	+ 5·64
05	−18·80	+ 1·17	+ 2·03	+ ·86	+ 2·36
1700	−21·67	+ ·09	+ 1·00	+ ·05	+ 1·55
1695	−23·95	− ·41	+ ·58	− ·17	+ 1·33
90	−28·35	− 2·69	− 1·66	− 2·22	− ·72
85	−31·48	− 4·13	− 3·04	− 3·36	− 1·86
80	−31·62	− 2·17	− 1·05	− 1·15	+ ·35
75	−32·74	− 1·40	− ·34	− ·09	+ 1·41
70	−33·80	− ·16	+ 1·05	+ 1·44	+ 2·94
65	−35·73	− ·20	+ 1·03	+ 1·65	+ 3·15
60	−36·90	+ ·49	+ 1·76	+ 2·65	+ 4·15
55	−37·35	+ ·74	+ 3·01	+ 3·13	+ 4·63
50	−40·48	− 2·26	− ·03	+ ·36	+ 1·86
45	−43·25	− 6·40	− 5·13	− 3·47	− 1·97
40	−42·76	− 7·57	− 6·31	− 4·40	− 2·90
35	−43·20	− 10·25	− 9·03	− 6·87	− 5·37
1630	−47·94	−16·66	−15·54	−13·09	−11·59

Tested by this criterion which has been laid down, Solution No. I. fails entirely even for the modern observations between 1900 and 1850, and the greater number of the residuals are far larger than is allowable with any permissible solution throughout the entire period 1900–1750. Diminishing the calculated values by a second of arc improves the solution, but still leaves the outstanding residuals far too large during the greater part of the period 1900–1750, the discordances ranging between $+2''\cdot98$ and $-2''\cdot29$, instead of never exceeding a second of arc. When the comparison is carried into the earlier epochs before 1750, the calculated values fail altogether adequately to represent the observations, and are quite discordant with the results obtained from the numerous occultations of stars during the periods 1740–1710 and 1690–1670.

Solution No. III. breaks down completely as thus tested, not only for the earlier observations, but likewise for the modern ones, the discordances between the calculated and observed errors ranging from $+2''\cdot60$ in 1800 to $-2''\cdot66$ in 1895; whilst they run up to over $6''$ between 1730 and 1710.

Solution No. IV. evidently requires a further correction to the epoch, and the calculated values should be decreased by about $1''\cdot5$. As thus modified the values are treated as Solution IV.* This modified solution represents the more modern observed errors of the tables with greater closeness than either of the others, as the discordances range only between $+1''\cdot32$ in

1815 to $-1''\cdot73$ in 1895. These are still far too large, however, and like the other solutions it fails completely to represent the earlier occultations of stars, the discordance rising to over 6″ between 1735 and 1710.

It is not surprising that Mr. Cowell's solutions fail to represent the earlier observations, for he has deduced his values solely from the Greenwich observations between 1900 and 1750. But this century and a half is quite insufficient to determine properly the values of inequalities with periods of from 300 to 400 years. For it is possible to find small portions of the arc of a number of terms with very variable parameters and periods which will represent the very simple fixed observed curve of error. And this is rendered still easier by the assumption of suitable empirical terms of shorter period which will serve to bring the radius of curvature at the middle and ends of the adopted curve into better accord with the curve of observed tabular error. But though this shorter portion of these different curves may thus be brought roughly into accord with the observed curve of tabular error during the century and a half between 1900 and 1750, there is no security that the remaining portion forming the larger half of the complete curve shall not be utterly discordant with each other and run altogether away from the curve of observed tabular error. It is only when the observations of the century prior to 1750 are taken into account that it becomes possible to properly test the manner in which the adopted term of very long period represents the observations, as it enables the comparison to be extended over the whole, or nearly the whole, arc of curvature.

A critical examination of the manner in which the observed values are represented by the separate constituents of Mr. Cowell's empirical solutions will show that the observations prior to 1750 cannot be satisfied by any term with a period much more than 300 years, and that his corrections would be improved by bringing the period of the principal empirical term nearer to 300 years and slightly shifting forward the epochs. And there can be little doubt that Mr. Cowell's empirical argument

$$\sin\{1^\circ\cdot10(Y-1850\cdot50)+152^\circ\cdot1\}$$

is identical with the argument shown by theory to exist in the expression for the Moon's longitude with the form

$$\sin\{3V-7E+4M+326^\circ\cdot8\}$$

which can be written as

$$\sin\{1^\circ\cdot19(Y-1850\cdot50)+153^\circ\cdot3\}$$

Only Mr. Cowell's coefficient is much greater than that assigned by theory.

Similarly an examination of the way in which the observed

values are represented by Mr. Cowell's two auxiliary terms of shorter period will show that the full coefficients are only required by the observations between 1870 and 1780, much smaller values being indicated by the observations at the ends of the series of a hundred and fifty years' observations, whilst the observations for the period prior to 1730 would be far better represented by changing the signs of the coefficients. In fact, the terms would much better represent the observation if their coefficients were written in the form

$$+2''.35 \cos\{1^\circ.2[Y-1850.5]+30^\circ\}$$
$$+\ .73 \cos\{1.2[Y-1850.5]+20\}$$

This would indicate that the terms were really compound terms due to the apparent coalescence of pairs of terms of similar period with the arguments of annual increment

$$5^\circ.44-1^\circ.20=4^\circ.24$$
$$5.44+1.20=6.44$$

and

$$8.60-1.20=7.40$$
$$8.60+1.20=9.80$$

and should be written in the form

$$+2''.35\{\tfrac{1}{2}.\,a_1 \sin(4^\circ.24[Y-1850.5]+220^\circ)$$
$$+\tfrac{1}{2}b_1 \sin(6^\circ.44[Y-1850.5]+250^\circ)\}$$
$$+0''.73\{\tfrac{1}{2}.\,a_2 \sin(7^\circ.40[Y-1850.5]+205^\circ)$$
$$+\tfrac{1}{2}b_2 \sin(9^\circ.80[Y-1850.5]+185^\circ)\}$$

where a_1 b_1, a_2 b_2 are numerical fractions differing little from unity.

(5) The next matter to be considered is the manner in which Mr. Cowell has dealt with the coefficients of the terms of shorter period whose values he has deduced from the observations made at Greenwich between 1900 and 1750. I do not think that he has done justice to his own results, especially in the case of terms arising from the disturbing action of the planets and that in his anxiety to reconcile his results with those derived from theory by M. Radau, he has often failed to realise the true meaning of the results he has obtained.

Mr. Cowell's three periods (i), (ii), (iii) depend on the observations of the periods 1750–1805, 1806–1851, and 1847–1901 respectively, each covering about fifty years, so that the probable errors of the values of the coefficients of his arguments should certainly not exceed $\pm 0''.05$ for period (i), nor $\pm 0''.04$ for period (ii), nor $\pm 0''.03$ for period (iii), and quantities twice as large as these probable errors cannot be passed over as due to accidental errors, but must be taken into account. Yet

Mr. Cowell frequently ignores much larger quantities than these as due to accidental errors, or as being unimportant, or at any rate as something which may be disregarded. This is especially so when they form the coefficient of a cosine term for which he fails to find any theoretical equivalent. But this is not doing justice to his own results, and is certainly not permissible. These coefficients must be shown to be due to the accumulation of accidental error, or to be the consequence of errors of observation or reduction, or to arise from the systematic influence of some other term. This must not be assumed.

When the observations yield as a correction to the tabular term

$$A \sin a$$

the terms

$$a' \sin a + a'' \cos a$$

unless a', the coefficient of the sine of the argument, is at least twice as large as a'', the coefficient of the cosine term, it cannot be used as a real quantity to be applied as a correction to the tabular coefficient A, but must be considered a quantity with a probable uncertainty at least as great as a''. For if the observed values are affected by errors of such magnitude or character that the coefficient a'' can be regarded as due to them, then the coefficient a' must be held to be equally liable to them and as uncertain in consequence by at least the amount of a''. On the other hand, if the coefficient a'' be held to be due to some small associated term of similar period, then a' will be just as likely to be similarly affected to the same extent. Yet Mr. Cowell frequently ignores this, and holds the sine coefficient as real and usable as a correction whilst the larger cosine coefficient is dismissed as fictitious. Thus, he deduces the following correction to the *evection* from the observations of the period 1847–1901

$$+0''{\cdot}03 \sin (2D-g) - 0''{\cdot}31 \cos (2D-g)$$

and says: "The observed and theoretical *evection* are in close accordance. This disposes of a correction of Hansen's" (*Monthly Notices*, 1904 December, p. 148). Yet how can this be justified in the face of the *cosine* term with a coefficient of $-0''{\cdot}31$? If the coefficient of the *cosine* term is due to the effects of errors of observation or reduction, then the coefficient of the *sine* term must be held to be equally uncertain by $\pm 0''{\cdot}31$; and if the coefficient of the cosine term be held due to some associated term of analogous period, then equally this associated term may similarly affect the sine term. In either case the true value of the coefficient of the sine term may have any value within $\pm 0''{\cdot}40$, and cannot be held to show that the theoretical and observed values are in close accord. Nor is it possible to dispose of the large coefficient of the cosine term by ascribing it to an error in tabular place of the *perigee*, because, if so, the coefficient

of the cosine of the mean anomaly should be five times as large and of the opposite sign, whereas it is only half as great and of the same sign.

This tendency to ignore inconvenient factors is very noticeable in the case of the terms due to the disturbing action of the planets when the value of the coefficients deduced from the observations is inconsistent with the theoretical values calculated by M. Radau. Mr. Cowell, then, often fails to do justice to his own results, and so has overlooked most important deductions.

Thus, in the case of the term to which M. Radau assigns the value

$$-0''\cdot348 \sin (2V-3E+85^\circ)$$

Mr. Cowell deduces the values

$$\begin{array}{llll} \text{Period} & \text{(i)} & -\ ''\cdot44 \sin (2V-3E+85^\circ) & +\ ''\cdot05 \cos (2V-3E+85^\circ) \\ & \text{(ii)} & -\ \cdot40 \sin (\quad ,, \quad) & -\ \cdot13 \cos (\quad ,, \quad) \\ & \text{(iii)} & -\ \cdot24 \sin (\quad ,, \quad) & +\ \cdot22 \cos (\quad ,, \quad) \end{array}$$

and adopts the value

$$-0''\cdot30 \sin (2V-3E+85^\circ)$$

leaving the residuals

$$\begin{array}{lll} \text{(i)} & -\ ''\cdot14 \sin (2V-3E+85^\circ) & +\ ''\cdot05 \cos (2V-3E+85^\circ) \\ \text{(ii)} & -\ \cdot10 \sin (\quad ,, \quad) & -\ \cdot13 \cos (\quad ,, \quad) \\ \text{(iii)} & +\ \cdot06 \sin (\quad ,, \quad) & +\ \cdot22 \cos (\quad ,, \quad) \end{array}$$

These are all much larger than is consistent with their being the results of mere errors of observation or reduction, and to ignore them is merely to neglect the evidence of the existence of other terms of long period than those considered by Mr. Cowell. For example, suppose these discordances due to an associated term differing in the annual increment of its argument by about $1^\circ\cdot5$, and having a coefficient of about $+0''\cdot30$ and an epoch near 1848. The elimination of the effects of such a term from the preceding residuals would leave them approximately as

$$\begin{array}{lll} \text{(i)} & -\ ''\cdot06 \sin (2V-3E+85^\circ) & +\ ''\cdot33 \cos (2V-3E+85^\circ) \\ \text{(ii)} & -\ \cdot36 \sin (\quad ,, \quad) & +\ \cdot02 \cos (\quad ,, \quad) \\ \text{(iii)} & -\ \cdot17 \sin (\quad ,, \quad) & +\ \cdot03 \cos (\quad ,, \quad) \end{array}$$

and so show that the value of the coefficient deduced by Mr. Cowell, on allowing for the superior weight of the modern observations, should be increased by over $0''\cdot20$, or be brought up to

$$-0''\cdot50 \sin (2V-3E+85^\circ)$$

There is nothing forced in the assumption of such a term. For example, the term depending on the argument

$$g - 20\mathrm{V} + 19\mathrm{E}$$

is of the required character. And the very possibility of such a result shows that it is impossible to pass over such residuals as these and adopt the mean of the sine coefficient as indicating the true correction for the coefficient of the term under investigation.

It will be noticed that in the case just supposed there is left an outstanding residual of some dimensions in the values deduced from period (i). That suffices to show that the hypothetical correction assumed really fails to properly meet all the facts, and that the true correction is rather more complex than that assumed. But Mr. Cowell does not hesitate to leave far larger residuals. There is the case of the term arising from the disturbing action of *Jupiter* to which M. Radau assigns the value

$$-0''\cdot139 \sin(\mathrm{J} + 99^\circ)$$

Mr. Cowell deduces from the observation the values

$$\begin{array}{lll} \text{Period (i)} & -0''\cdot50 \sin(\mathrm{J}+99^\circ) & +0''\cdot44 \cos(\mathrm{J}+99^\circ) \\ \text{(ii)} & -\ \cdot19 \sin(\ ,,\ ) & -\ \cdot15 \cos(\ ,,\ ) \\ \text{(iii)} & -\ \cdot14 \sin(\ ,,\ ) & -\ \cdot06 \cos(\ ,,\ ) \end{array}$$

and adopts the value

$$-0''\cdot10 \sin(\mathrm{J} + 99^\circ)$$

leaving outstanding the residuals

$$\begin{array}{lll} \text{(i)} & -0''\cdot40 \sin(\mathrm{J}+99^\circ) & +0''\cdot44 \cos(\mathrm{J}+99^\circ) \\ \text{(ii)} & -\ \cdot09 \sin(\ ,,\ ) & -\ \cdot15 \cos(\ ,,\ ) \\ \text{(iii)} & -\ \cdot04 \sin(\ ,,\ ) & -\ \cdot06 \cos(\ ,,\ ) \end{array}$$

But residuals of this character cannot be passed over in silence. The very large outstanding residuals left for the first period cannot be ascribed to mere imperfections in the earlier observations unless Mr. Cowell is prepared to throw over the whole of the results he has deduced from the observations of this period (i); for what value can be possessed by numerous corrections ranging between $+0''\cdot05$ and $+0''\cdot15$ if the observations are so imperfect that the values deduced are liable to discordances amounting to $\pm 0''\cdot40$? Obviously the true cause for these residuals is not imperfections in the observations, but that the values deduced from the coefficients of this particular argument are affected by systematic errors, probably due to the existence of two or more terms of similar period; and until the influence of

the disturbing causes is traced and eliminated, the value deduced for the coefficient must be deemed most uncertain.

As a matter of fact there are a number of terms giving rise to systematic variations in the apparent value of the coefficients of this term depending on the perturbations of *Jupiter*. For instance, the terms depending on the arguments

$2\varpi + 3V - 5E$	Annual increment	$= +36^\circ.92$
$2\varpi + 2E - 4M$	" "	$= +35.73$
$\beta - 20V + 19E$	" "	$= -31.68$

As the annual increment of the argument of these terms lies between that of the two terms

J	Annual increment	$= +30^\circ.67$
and $\omega - \omega'$	" "	$= +40.67$

the existence of these disturbing terms should give rise likewise to apparent discordances in the values deduced from observation for the coefficients of the latter argument. References to Mr. Cowell's results show that this is the case, as he obtains the values

$$\begin{array}{lll} \text{Period (i)} & +1''.03 \sin(\omega-\omega') - 0''.15 \cos(\omega-\omega') \\ \text{(ii)} & +\ .73 \sin(\ \text{,,}\ ) - .43 \cos(\ \text{,,}\ ) \\ \text{(iii)} & +\ .55 \sin(\ \text{,,}\ ) - .36 \cos(\ \text{,,}\ ) \end{array}$$

Mr. Cowell, however, as usual, ignores these large residuals depending on the cosine of the argument, but treats the coefficient of the sine of the argument as indicating that Hansen's tabular value for this term should be reduced from

$$+1''.58 \sin(\omega-\omega')$$

to

$$+1.60 \sin(\omega-\omega')$$

and therefore that Delaunay's value of

$$+0''.87 \sin(\omega-\omega')$$

is more accurate than the value

$$+1''.33 \sin(\omega-\omega')$$

deduced by Hansen in the *Darlegung*.

In the face of the large residuals depending on the cosine of this argument, the value deduced from the observations for the coefficient of the sine of the argument must be held to be uncertain by at least $\pm 0''.40$, and hence no such conclusion

can be legitimately drawn. In fact, the true coefficient of this term lies between $1''\cdot10$ and $1''\cdot18$, being probably very close to $+1''\cdot13$.

It will be noticed that the discordance in the coefficient of this term is much greater than even in the case of the term depending on J. This is because there are yet other terms exerting a systematic influence on these coefficients in addition to those already given; but lying on the other side of the argument $(\omega-\omega')$ they do not exert a corresponding influence on the coefficients of the J term. These are the terms depending on the arguments

$$g-21V+21E = +43^{\circ}\cdot11 \quad \text{Annual increment}$$
$$3V-5E = -44\cdot53 \quad ,, \quad ,,$$
$$2E-4M = -45\cdot64 \quad ,, \quad ,,$$

besides the term of different character depending on the argument

$$2\Omega = -38^{\circ}\cdot68$$

In consequence of the existence of these disturbing terms the coefficients of this argument $(\omega-\omega')$ deduced by Mr. Cowell from the observations are really compound functions of the coefficients of at least seven other terms of similar period, and cannot be treated as giving any information as they stand as to the true correction to Hansen's tabular value of this term depending on the argument $(\omega-\omega')$.

Exactly the same thing occurs with the coefficients of the term to which M. Radau assigns the value

$$-0''\cdot112 \sin(2E-4M+293^{\circ})$$

Mr. Cowell deduces from observation the values

$$\begin{array}{lllll}
\text{Period} & \text{(i)} & -0''\cdot12 \sin(2E-4M+82^{\circ}) & -0''\cdot33 \cos(2E-4M+82^{\circ}) \\
 & \text{(ii)} & -\ \cdot13 \sin(\quad ,, \quad) & +\ \cdot18 \cos(\quad ,, \quad) \\
 & \text{(iii)} & +\ \cdot01 \sin(\quad ,, \quad) & +\ \cdot11 \cos(\quad ,, \quad)
\end{array}$$

Here, again, the residuals are far greater than can be disregarded, showing the values obtained to represent the combined effects of two or more similar terms. As the two terms depending on the arguments

$$2E-4M$$

and

$$3V-5E$$

only differ in annual increment by a little over a degree a year, the values deduced by Mr. Cowell must represent the combined effects of the two terms. The values given by Mr. Cowell do

not suffice to even roughly separate their values, but would indicate the values

$$+0''.20 \sin \{2E-4M+220°\}$$
$$+0.30 \sin \{3V-5E+ 70°\}$$

The values deduced from the observation are also affected by the terms depending on the arguments

$$g-(21V-21E)$$
$$\varpi-\varpi'$$

An important case is that of the term with the argument

$$E-J$$

Mr. Cowell deduces for the coefficient of this term the values

Periods (i) and (ii)	$+0''.68 \sin (E-J)$	$+0''.07 \cos (E-J)$
(iii)	$+ \cdot 73 \sin (E-J)$	$+ \cdot 13 \cos (E-J)$

In both cases the coefficient of the cosine term is too large to be disregarded as done by Mr. Cowell, and their existence shows that the values obtained are affected by some small allied term of closely similar period, and in consequence the coefficient deduced by Mr. Cowell must be regarded as uncertain by fully $\pm 0''\cdot 10$.

Large residuals of similar nature are also ignored by Mr. Cowell in connection with the arguments

$$(2\omega-2\omega') \qquad 2\omega \qquad g+2\omega \qquad 2g$$

and consequently in all these cases the corrections he has adopted to the tabular coefficients must be regarded as uncertain.

In a certain number of cases Mr. Cowell points out that the correction to the coefficients he deduces to two or more terms are so related that they cannot be regarded as independent; in fact, in these cases he takes into account the very conditions which he has neglected in the cases dealt with above. But he treats these cases somewhat arbitrarily, apparently swayed by the desire to bring the results as close to M. Radau's values as can be done, instead of deducing the values indicated by the results themselves by treating them as a system of simultaneous equations.

Thus dealing with the coefficients of the terms depending on the two arguments

$$D+g'$$
$$2D-g+3V-3E$$

Mr. Cowell points out that these two arguments differ so slightly

in period that for long intervals of time the coefficients deduced from the observations for the one term must involve the coefficients of the other. He obtains for the terms the following values :—

Period.	sin (D+g').	cos (D+g').	sin (2D−g +3V−3E).	cos (2D−g +3V−3E).
(i)	+17″·63	+0″·04	−0″·58	−0″·02
(ii)	+17·01	− ·02	− ·90	+ ·30
(iii)	+17·47	− ·29	−1·07	+ ·27

But instead of deducing from these values treated as simultaneous equations the actual results indicated by themselves, Mr. Cowell arbitrarily assumes the values

$$+17''\!\cdot\!50 \sin(\;D+g'\qquad\qquad)$$
$$-\;0\cdot70 \sin(2D-g+3V-3E)$$

and points out that these values reduce the residuals left outstanding to the small quantities.

Period.	sin (D+g').	cos (D+g').	sin (2D−g +3V−3E).	cos (2D−g +3V−3E).
(i)	−″·24	+″·15	−″·09	−″·08
(ii)	−·07	−·23	+·03	+·42
(iii)	−·00	−·29	+·02	+·16

But here, again, the outstanding residuals are far larger than can be explained otherwise than by the existence of an associated term which Mr. Cowell has omitted to take into consideration.*

* The large value found from the observations of the period 1847–1901 for the cosine of the argument

$$D+g'=g+\omega-\omega'=g+\varpi-\varpi'$$

had specially attracted Mr. Cowell's attention in his earlier investigation (*Monthly Notices*, 1904 March, pp. 419–420). He then assigned to this term the value

$$-0''\!\cdot\!46 \cos(g+\varpi-\varpi')$$

and suggested that its origin might be an error in the value, derived from theory, which he had adopted for the coefficient of the term depending on the argument

$$2D-g+3V-3E$$

or possibly that the true argument of the term might really be $g+\varpi$, the Moon's longitude ("since ϖ' is practically a constant, analyses of the errors cannot possibly distinguish between $g+\varpi$ and $g+\varpi-\varpi'$") and so may be due to systematic errors of observation. Later (*Monthly Notices*, 1904 June, p. 292) Mr. Cowell elaborates the idea and suggests that the principal portion of this term is really of the form

$$-0''\!\cdot\!40 \cos(g+\varpi=l)$$

But this arbitrary treatment should be avoided and the values deduced from observation treated as a set of twelve simultaneous equations between the coefficients of the terms

$$Q' \sin(D+g') + Q'' \cos(D+g') + V' \sin(2D-g+3V-3E) \\ + V'' \cos(2D-g+3V-3E)$$

and the values deduced from the normal equations

$$\begin{array}{llllll} +4{\cdot}01Q' + & {\cdot}00Q'' - & {\cdot}80V' + & {\cdot}02V'' & = & +1''{\cdot}14 \\ + \ {\cdot}00 & +4{\cdot}01 & - \ {\cdot}02 & - \ {\cdot}80 & = & + \ {\cdot}23 \\ - \ {\cdot}80 & - \ {\cdot}02 & +4{\cdot}01 & + \ {\cdot}00 & = & +2{\cdot}33 \\ + \ {\cdot}02 & - \ {\cdot}80 & + \ {\cdot}00 & +4{\cdot}01 & = & - \ {\cdot}90 \end{array}$$

which yield the values

$$V' = +0''{\cdot}665 \qquad Q' = +0''{\cdot}414$$
$$V'' = -0{\cdot}247 \qquad Q'' = +0{\cdot}012$$

corresponding to the values

$$+17''{\cdot}482 \sin(D+g')$$
$$+ \ 0{\cdot}710 \sin(2D-g+3V-3E+340°)$$

and arises partly from the constant correction of $-1''{\cdot}00$ that Hansen has applied to all the tabular latitudes together with a possible constant error of similar amount in the observed declinations, due to refraction or some such cause, whilst the remainder might be due to an erroneous value of the lunar parallax. This latter view is repeated in the conclusion of his last paper (*Monthly Notices*, 1905 January, p. 275).

But Mr. Cowell has overlooked the fact that ϖ' though a constant has yet the value $279°{\cdot}5$, so that

$$-0''{\cdot}46 \cos(g+\varpi-\varpi') = -0''{\cdot}46 \cos(g+\varpi-279°{\cdot}5) = -0''{\cdot}45 \sin(g+\varpi) \\ +0''{\cdot}07 \cos(g+\varpi)$$

so that any correction of the form

$$-0''{\cdot}40 \cos(g+\varpi = l)$$

would correspond with

$$-0''{\cdot}39 \sin(g+\varpi-\varpi')$$

and not with

$$-0''{\cdot}39 \cos(g+\varpi-\varpi')$$

Hence the cause he suggests will not explain the origin of this cosine term, though it does serve to explain the origin of a considerable part of the corresponding sine term.

In Table X. (*Monthly Notices*, 1904 December) Mr. Cowell has reduced the value of this cosine term to

$$-0''{\cdot}29 \cos(g+\varpi-\varpi')$$

but he gives no reason for the reduction.

The residuals left outstanding by this solution are

Period.	sin $(D+g')$.	cos $(D+g')$.	sin $(2D-g+3V-3E)$.	cos $(2D-g+3V-3E)$.
(i)	$-0''.22$	$+0''.06$	$-0''.12$	$-0''.20$
(ii)	+ ·00	+ ·04	+ ·02	− ·08
(iii)	+ ·14	− ·16	+ ·03	+ ·14

It will be seen that in this instance the values obtained for the coefficients of these terms does not differ from that assumed by Mr. Cowell by inspection, but that there is a sensible correction deduced to the epoch of the *Venus* term. The residuals are smaller than those left by Mr. Cowell's solution, and the large term depending on the cosine of the argument $(D+g')$ has been very much reduced. Yet the residuals which still exist are larger than they should be, and their gradual variation affords a strong indication that there exists an associated term of very similar period giving rise to periodical discordances of about three hundred years' period.

Such a term does exist, and depends on the argument

$$2D-g+4E-4M$$

The data given by Mr. Cowell do not serve to determine the value of the coefficient of this term, but it can easily be shown that the values

$$+0''.89 \sin(2D-g+3V-3E+340^\circ)$$
$$+0''.22 \sin(2D-g+4E-4M)$$

will represent the observed values with considerable accuracy. Both these terms have coefficients about a fifth of a second larger than that deduced from theory by M. Radau—a feature common to most of the coefficients of the planetary terms of this character when deduced from the observations.

Mr. Cowell adopts a similar method for dealing with the associated terms depending on the arguments

$$2D-g+2E-2J$$
$$g-\Omega$$

From the observations he deduces the values

Period.	sin $(2D-g+2E-2J)$.	cos $(2D-g+2E-2J)$.	sin $(g-\Omega)$.	cos $(g-\Omega)$.
(i)	$-1''.02$	$-0''.46$	$-0''.51$	$-0''.09$
(ii)	−1·44	− ·06	− ·57	− ·15
(iii)	−1·13	− ·03	− ·66	− ·19

He then assumes that the values of the coefficients are

$$-1''.00 \sin(2D-g+2E-2J) \qquad -0''.50 \sin(g-\Omega)$$

and calculates the consequent correction to the apparent values of the coefficients deduced from the observations showing that the adopted values leave outstanding the residuals

Period.	sin (2D − g + 2E − 2J).	cos (2D − g + 2E − 2J).	sin (g − Ω).	cos (g − Ω).
(i)	+0″·17	+0″·01	+0″·03	−0″·19
(ii)	+ ·06	− ·08	+ ·04	− ·15
(iii)	− ·12	− ·05	− ·06	− ·10

These are too large, especially in the case of the cosine of the argument $(g - \Omega)$.

Treating the values as twelve simultaneous equations in the same manner as before, the resulting normal equations yield the values

$$
\begin{aligned}
&-1''\cdot015 \sin(2D - g + 2E - 2J + 355^\circ) \\
&-0\cdot525 \sin(g - \Omega) \\
&-0\cdot181 \cos(g - \Omega)
\end{aligned}
$$

leaving residuals in all cases under $\pm 0''\cdot 05$.

The data given by Mr. Cowell in an earlier paper (*Monthly Notices*, 1904 March, p. 417) are more complete, and suffice to determine the coefficient of the allied term depending on the argument $(g - 2\varpi + 2J)$, as well as that of the *Jovian evection.* From the observations for the period 1847–1901 (iii) he deduces the values

$$
\begin{aligned}
&\{-0''\cdot02 \sin(2\varpi - 2J) - 0''\cdot98 \cos(2\varpi - 2J)\} \sin g \\
&\{-1\cdot26 \sin(2\varpi - 2J) + 0\cdot17 \cos(2\varpi - 2J)\} \cos g
\end{aligned}
$$

from which, by omitting small terms, he derives the value

$$-1''\cdot12 \sin(g + 2\varpi - 2J)$$

The complete values are

$$
\begin{aligned}
&-1''\cdot123 \sin(g + 2\omega - 2J) + 0''\cdot075 \cos(g + 2\varpi - 2J) \\
&\qquad = -1''\cdot125 \sin(g + 2\varpi - 2J + 356^\circ) \\
&+0''\cdot140 \sin(g - 2\omega + 2J) + 0''\cdot095 \cos(g - 2\varpi - 2J) \\
&\qquad = +0''\cdot169 \sin(g - 2\varpi + 2J + 34^\circ)
\end{aligned}
$$

It will be seen that the small terms neglected by Mr. Cowell are nearly as large as the correction he adopts and larger than many terms he takes into account.

At the same time Mr. Cowell gives the results

$$+0''\cdot52 \cos(2\varpi - 3J + 7^\circ) \sin g + 0''\cdot21 \sin(2\varpi - 3J + 7^\circ) \cos g$$

from which he deduces the value

$$+0''\cdot36 \sin(g + 2\varpi - 3J + 7^\circ)$$

but ignores the corresponding value

$$+0''\cdot 16 \sin(g-2\varpi+3J-7^\circ)$$

Yet this second term must be held as well established as the first, for if ascribed to accidental errors it must render the former too uncertain to possess any value. In his final values the results for this period are changed to

$$+0''\cdot 42 \sin(g+2\varpi-3J+7^\circ)+0''\cdot 13 \cos(g+2\varpi-3J+7^\circ)$$

and Mr. Cowell ignores the cosine term as usual.

The pair of terms depending on the arguments

$$3V-4E-2^\circ = E+(3V-5E)-2^\circ$$

and

$$g'-\omega+\omega' = g'-(\varpi-\varpi')$$

though bracketed by Mr. Cowell, on p. 135 of Table X., as requiring simultaneous treatment, have not been referred to in the notes, where the remainder of the associated terms are examined and their corrected values deduced. The values deduced from the observations are :—

	$\sin(3V-4E-2^\circ)$.	$\cos(3V-4E-2^\circ)$.	$\sin(g'-\varpi+\varpi')$.	$\cos(g'-\varpi+\varpi')$.
Periods (i) and (ii)	$-0''\cdot 16$	$-0''\cdot 27$	$+18''\cdot 43$	$+''\cdot 23$
(iii)	$-\cdot 10$	$-\cdot 08$	$+18\cdot 68$	$-\cdot 32$

and Mr. Cowell adopts the values

$$-0''\cdot 10 \sin(3V-4E-2^\circ) \qquad +18''\cdot 60 \sin(g'-\varpi+\varpi')$$

ignoring, as usual, the large cosine terms.

Yet with more care a much better result can be obtained from Mr. Cowell's data. For the united periods (i) and (ii) the two terms are independent of each other, and the values found may be taken as they stand as the values of their respective coefficients. The period (iii) extends over too short a period for this to be done, and the true values must be deduced from the simultaneous equations. They are

Period (iii) ...	$-0''\cdot 44$	$-0''\cdot 03$	$+18''\cdot 84$	$-0''\cdot 53$

These correspond to the terms

Periods (i) and (ii)	$+0''\cdot 31 \sin(3V-4E+237^\circ)$	$+0''\cdot 28 \sin(g-\varpi+\varpi'+126^\circ)$
(iii)	$+0\cdot 44 \sin(3V-4E+182)$	$+0\cdot 58 \sin(g-\varpi+\varpi'+294)$

in addition to the theoretical term

$$+18''\cdot 60 \sin(g-\varpi+\varpi')$$

To bring the constant factors of the preceding terms into harmony the argument of the *Venus* term must have its annual increment decreased by $55^\circ \div 73 = 0^\circ{\cdot}76$, and the annual increment of the second term must be increased by $168^\circ \div 73 = +2^\circ{\cdot}31$, making the annual increment of the two arguments differ from that of the Earth's mean longitude by $-45^\circ{\cdot}20$ in the first case and by $-38^\circ{\cdot}36$ in the second case. At the same time the decrease in the coefficients of the two terms shows that in each case it must represent the sum of at least two terms. In the first case the values deduced from the observations is the united effect of the terms depending on the arguments

$$3V - 4E$$

and

$$3E - 4M$$

Mr. Cowell's data do not suffice to determine the separate values of the coefficients of these two terms, but it can easily be shown that the observed values are entirely satisfied by the values

$$+0''{\cdot}548 \sin(3V - 4E + 201^\circ)$$
$$+0{\cdot}284 \sin(3E - 4M + 39)$$

These terms illustrate how two terms of considerable magnitude may for long periods mutually counterbalance each other and leave outstanding a compound term of much less magnitude. In the case of the second term the observed discordances can be explained by the allied terms depending on the pair of arguments

$$2D - 2g + 3V - 4E$$
$$2D - 2g + 3E - 4M$$

The most important instances of closely associated terms are those depending on the arguments

$$2M - E + 49^\circ$$
$$2\varpi - 2J$$
$$-\Omega$$

For the apparent value of the coefficients of these arguments Mr. Cowell obtains from the observations

	Period (i). Value.	Residual.	Period (ii). Value.	Residual.	Period (iii). Value.	Residual.	
$\sin(2M - E + 49^\circ)$	$-\ ''{\cdot}67$	$-''{\cdot}12$	$-\ ''{\cdot}52$	$+''{\cdot}02$	$+\ ''{\cdot}09$	$+''{\cdot}03$	$= M'$
$\cos(2M - E + 49)$	$-\ {\cdot}50$	$+{\cdot}06$	$+\ {\cdot}50$	$-{\cdot}02$	$+\ {\cdot}12$	$-{\cdot}17$	$= M''$
$\sin(2\varpi - 2J)$	$+\ {\cdot}67$	$-{\cdot}05$	$+\ {\cdot}39$	$-{\cdot}19$	$+\ {\cdot}59$	$+{\cdot}05$	$= J'$
$\cos(2\varpi - 2J)$	$-\ {\cdot}87$	$+{\cdot}31$	$-\ {\cdot}62$	$+{\cdot}04$	$-\ {\cdot}73$	$-{\cdot}23$	$= J''$
$\sin(-\Omega)$	$-6{\cdot}95$	$-{\cdot}18$	$-6{\cdot}39$	$-{\cdot}28$	$-6{\cdot}15$	$+{\cdot}40$	$= B' - 6''{\cdot}60$
$\cos(-\Omega)$	$-\ {\cdot}97$	$-{\cdot}c6$	$-\ {\cdot}66$	$+{\cdot}03$	$-\ {\cdot}59$	$-{\cdot}00$	$= B''$

To represent these values Mr. Cowell assumes that the true coefficients of the terms are

$$
\begin{aligned}
&-0''.40 \sin(2M-E+49^\circ)\\
&+0.20 \sin(2\varpi-2J)\\
&-6.60 \sin(-\Omega)\\
&-0.70 \cos(-\Omega)
\end{aligned}
$$

The outstanding residuals left by the substitution of these values is given under the heading "Residuals." They are considerable in magnitude, nearly half of them considerably exceeding a tenth of a second of arc, and the solution fails to represent even the latest and most accurate values of period (iii). In adopting these values Mr. Cowell appears to have been anxious to reduce the planetary terms to the small values indicated by M. Radau's theoretical calculations, and in so doing has thrown over the much more accurately calculated values of Mr. Hill for the terms depending on the figure of the Earth. But unless there is some serious defect in the theoretical basis of Mr. Hill's calculation of the values of the terms, due to the figure of the Earth, the values he has deduced must be close approximations to the true values, and cannot admit of such corrections as Mr. Cowell indicates. Is there any reason for supposing the method adopted to be defective? Hansen has obtained similar results by an entirely different method of admitted adequacy. Yet, unless the existence of these large errors be admitted, it follows that to represent the observations very much larger values must be adopted for the coefficients of other terms, due to the disturbing action of the planets; and it is solely by thus throwing the whole error on the theoretical coefficients of the terms depending on the longitude of the lunar node that it is possible to reduce the coefficients of the planetary terms to the small dimensions that have been adopted by Mr. Cowell.

The only satisfactory manner of treating this question is to derive the values directly from the observed results by solving the system of eighteen simultaneous equations by the method of least squares. Adopting Mr. Cowell's data, there are obtained the system of normal equations

$$
\begin{array}{lllllll}
+6.31M' & + .00M'' & -1.06J' & - .31J'' & +1.31B' & - .35B'' & =-2''.35\\
+ .00 & +6.31 & + .31 & -1.06 & + .35 & +1.31 & =-1.08\\
-1.06 & + .31 & +7.69 & + .00 & +4.70 & - .31 & =+1.79\\
- .31 & -1.06 & + .00 & +7.69 & + .31 & +4.70 & =-4.39\\
+1.31 & + .35 & +4.70 & + .37 & +6.85 & - .00 & =- .10\\
- .35 & +1.31 & - .31 & +4.70 & + .00 & +6.85 & =-5.41
\end{array}
$$

yielding the values

$$M' = -0''.372 \qquad J' = +0''.198 \qquad B' = -0''.066$$
$$M'' = -0.074 \qquad J' = -0.196 \qquad B'' = -0.652$$

corresponding to the term

$$\begin{aligned}&-0''.379 \sin (2M - E + 60^\circ)\\ &+0.279 \sin (2\omega - 2J + 315^\circ)\\ &-6.666 \sin (-\Omega)\\ &-0.652 \cos (-\Omega)\end{aligned}$$

It will be seen that these results confirm those adopted by Mr. Cowell in throwing the greater portion of the correction on to the coefficients of the theoretical ellipticity terms, yielding the above values instead of the theoretical values

$$\begin{aligned}&-7''.708 \sin (-\Omega)\\ &-0.292 \cos (-\Omega)\end{aligned}$$

The residuals left by these new values are smaller than those left by Mr. Cowell's solution, but the observed and calculated values of the coefficients of the Moon's node still show the large residuals.

	Period (i).	Period (ii).	Period (iii).
	$''$	$''$	$''$
$\sin(-\Omega)$	$-.02$	$-.17$	$+.33$
$\cos(-\Omega)$	$+.00$	$+.13$	$+.10$

Some disturbing cause must still remain outstanding. The residuals could be represented by increasing the coefficient of the term depending on the argument $(2\varpi - 2J)$ by one half, and introducing a small term depending on an argument of the form

$$\varpi + E - 2M$$

but the data given by Mr. Cowell are not sufficient to justify this course being adopted.*

* In the preceding I have assumed that Mr. Cowell has correctly stated the modified tabular coefficient used in Period (iii) as

$$-7''.34 \sin (-\Omega) - 0''.71 \cos (-\Omega)$$

But I can find no reference in his papers to the application of any correction to Hansen's tabular coefficient of *sin* (Ω); and if no correction has been applied the value used must be Hansen's tabular value unaltered or

$$-8''.12 \sin (-\Omega)$$

If by an oversight Mr. Cowell had subtracted instead of added the portion of the complete coefficient of the term in the expression for the true longitude

The results obtained indicate very strongly that the action of the planets gives rise to perturbations which are explicitly independent of the Moon's longitude, having coefficients much larger than those which can be theoretically deduced from the combined first powers of the disturbing action of the Sun and planets.

(6) It remains now to compare the values of the terms of longer period which have been deduced by Mr. Cowell from the observations, with the standard observed errors of the tables.

Let "Hansen (modified)" denote Hansen's tabular value after the removal of all the planetary terms. Then the correction to this modified value deduced by Mr. Cowell from the discussion of the observations, after omitting the smaller correction to the terms of shorter period, may be written as

which is derived from the reduction to the ecliptic, it would account for the discrepancy as

$$-\{+7''\cdot734-0''\cdot388=+7''\cdot346\}\sin(-\Omega)$$

instead of

$$-\{+8''\cdot122\}\sin(-\Omega)$$

But in this case the preceding would want revising, as the observed value for the Period (iii) would be

$$-6''\cdot94\sin(-\Omega)$$

instead of

$$-6''\cdot15\sin(-\Omega)$$

and Mr. Cowell's residual be $-0''\cdot38$ instead of $+0''\cdot40$.

The amended normal equation yield now the values

$$\begin{aligned}&-0''\cdot556\sin(2M-E+57^\circ)\\&+0\cdot173\sin(2\varpi-2J+\ \ 1^\circ)\\&-6\cdot872\sin(-\Omega)\\&-0\cdot794\cos(-\Omega)\end{aligned}$$

and the large residuals in sin Ω are much decreased, they being

	Period (i).	Period (ii)	Period (iii).
$\sin(-\Omega)$	$+\cdot18$	$-\cdot08$	$+\cdot01$
$\cos(-\Omega)$	$+\cdot07$	$+\cdot06$	$+\cdot13$

If this view be correct, then the residuals between Mr. Cowell's adopted and the observed values of the coefficient of sin Ω would be

Period (i) $=-0''\cdot18$ Period (ii) $=-0''\cdot28$ Period (iii) $=-0''\cdot38$

so that he would have increased his adopted value by about $-0''\cdot30$ or brought it up to

$$-6''\cdot90\sin(-\Omega)$$

leaving the residuals

Period (i) $=+0''\cdot12$ Period (ii) $=+0''\cdot02$ Period (iii) $=-0''\cdot08$

$$
\begin{aligned}
\text{Cowell's Correction} = & - 2''{\cdot}84 \\
& - 30{\cdot}67(T - 180^\circ) \\
& - 5{\cdot}96(T - 180^\circ)^2 \\
& + 14{\cdot}40 \sin\{18V - 16E - g + 30{\cdot}6\} \\
& + 0{\cdot}27 \sin\{8V - 13E + 228{\cdot}0\} \\
& - 0{\cdot}80 \sin\{V - E\} \\
& + 0{\cdot}30 \sin\{2V - 2E\} \\
& - 0{\cdot}30 \sin\{2V - 3E + 85\} \\
& - 0{\cdot}10 \sin\{3V - 4E + 88\} \\
& + 0{\cdot}40 \sin\{E - 2M - 49\} \\
& + 0{\cdot}30 \sin\{2E - 2M\} \\
& + 0{\cdot}15 \sin\{2E - 4M + 317\} \\
& + 0{\cdot}70 \sin\{E - J\} \\
& + 0{\cdot}20 \sin\{E - 2J + 298\} \\
& - 0{\cdot}20 \sin\{2E - 2J\} \\
& - 0{\cdot}10 \sin\{J + 99\} \\
& + 0{\cdot}20 \sin\{2D - 2g + (2E - 2J)\} \\
& - 0{\cdot}10 \sin\{g - (3V - 3E)\} \\
& - 0{\cdot}30 \sin\{g - (2E - 2J)\} \\
& + 0{\cdot}10 \sin\{2D - g - (V - E)\} \\
& - 0{\cdot}10 \sin\{2D - g - (2V - 2E)\} \\
& - 0{\cdot}70 \sin\{2D - g + (3V - 3E)\} \\
& + 0{\cdot}20 \sin\{2D - g + (E - J)\} \\
& - 0{\cdot}20 \sin\{2D - g - (E - J)\} \\
& - 1{\cdot}10 \sin\{2D - g + (2E - 2J)\} \\
& + 0{\cdot}40 \sin\{2D - g + (2E - 3J)\} \\
& - 0{\cdot}10 \sin\{2D - (V - E)\} \\
& - 0{\cdot}10 \sin\{2D - (2V - 2E)\} \\
& - 0{\cdot}20 \sin\{2D - (E - J)\} \\
& - 1{\cdot}22 \sin\{\Omega\} \\
& + 0{\cdot}23 \sin\{g + \Omega\} \\
& - 0{\cdot}23 \sin\{g - \Omega\} \\
& - 0{\cdot}58 \sin\{\varpi - \varpi'\} \\
& + 0{\cdot}07 \sin\{2\varpi - 2\varpi'\} \\
& + 0{\cdot}15 \sin\{2\varpi\} \\
& - 0{\cdot}55 \sin\{g'\} \\
& - 0{\cdot}55 \sin\{g' - \varpi + \varpi'\}
\end{aligned}
$$

$$
\begin{aligned}
\text{Cowell's corrections} = &- 0''.67 \sin \{ g \} \\
&+ 1.56 \sin \{ D \} \\
&- 0.67 \sin \{ D+g' \} \\
&- 0.25 \sin \{ 2D-g \} \\
&+ 12''.16 \sin \{ 1''.10[Y-1850.5]+153^\circ \} \\
&+ 2.35 \sin \{ 5.43[Y-1850.5]+55 \} \\
&+ 0.73 \sin \{ 8.60[Y-1850.5]+15 \} \\
&- 1.50
\end{aligned}
$$

The three last inequalities are Mr. Cowell's three empirical terms, and to them has been added the further correction to the epochs which has been already shown to be indicated by the observations.

Then the comparison between the calculated and observed mean yearly error of Hansen's tables yields the values given beneath under the heading "Cowell" for the discordance between the amended tables and the Greenwich Transit Circle observations:—

	"Cowell."		"Cowell Supplemented."			"Cowell."		"Cowell Supplemented."	
	Annual.	Tri-annual.	Annual.	Tri-annual.		Annual.	Tri-annual.	Annual.	Tri-annual.
	″	″	″	″		″	″	″	″
1902	−1·03	...	− ·47	...	1883	−1·27	−1·14	− ·29	− ·16
01	− ·62	−1·01	− ·21	− ·54	82	−1·17	...	− ·18	...
1900	−1·39	...	− ·94	...	81	−1·58	...	− ·58	...
1899	− ·15	...	+ ·35	...	80	−1·60	−1·49	− ·60	− ·49
98	− ·66	− ·61	− ·12	− ·07	79	−1·29	...	− ·29	...
97	−1·02	...	− ·43	...	78	−1·25	...	− ·25	...
96	− ·56	...	+ ·07	...	77	− ·53	− ·48	+ ·47	+ ·52
95	− ·75	− ·75	− ·08	− ·08	76	+ ·34	...	+1·35	...
94	− ·95	...	− ·24	...	75	− ·29	...	+ ·67	...
93	− ·94	...	− ·20	...	74	− ·43	− ·23	+ ·52	+ ·72
92	−1·35	−1·31	− ·57	− ·54	73	+ ·05	...	+ ·98	...
91	−1·65	...	− ·84	...	72	− ·51	...	+ ·40	...
90	−1·99	...	−1·15	...	71	− ·07	− ·38	+ ·82	+ ·51
89	−1·33	−1·44	− ·46	− ·68	70	− ·56	...	+ ·31	...
88	−1·33	...	− ·44	...	69	− ·33	...	+ ·51	...
87	− ·95	...	− ·04	...	68	+ ·21	− ·04	+1·02	+ ·77
86	− ·14	− ·65	+ ·79	+ ·28	67	+ ·01	...	+ ·78	...
85	− ·85	...	+ ·10	...	66	+ ·09	...	+ ·83	...
84	− ·97	...	+ ·00	...	65	− ·42	− ·35	+ ·29	+ ·36

	"Cowell."		"Cowell Supplemented."	
	Annual.	Tri-annual.	Annual.	Tri-annual.
	"	"	"	"
1864	− ·71	...	− ·04	...
63	−1·12	...	− ·49	...
62	−1·12	−1·16	− ·53	− ·57
61	−1·25	...	− ·70	...
60	−1·30	...	− ·80	...
59	−1·20	−1·27	− ·75	− ·81
58	−1·30	...	− ·89	...
1857	−1·43	...	−1·07	...
56	−1·45	−1·31	−1·14	−1·00
55	−1·04	...	− ·78	...
54	−1·12	...	− ·91	...
53	− ·81	−1·04	− ·65	− ·88
52	−1·20	...	−1·09	...
1851	− ·77	...	− ·72	...

It is apparent that a further correction to the epoch of $-0''\cdot80$ would bring the calculated and observed values into much closer accord, but such a correction cannot be made without throwing the earlier observations, made between 1850 and 1750, into discordance with observation far greater than is permissible ; for if the observations from 1900–1850 are such as to require a decrease of the epoch by about $0''\cdot8$, the observations for 1820–1770 require an increase of at least as much.

The comparison indicates a term of approximately the form

$$-1''\cdot00 \sin \{3^\circ\cdot0[Y-1850\cdot5]\}$$

Supposing Mr. Cowell's values supplemented by the addition of such a term, the discordances are reduced to the values shown under the heading "Cowell Supplemented." It brings the calculated and the observed errors into much closer agreement. Probably a still better result, as far as these modern observations are concerned, would be gained by using a correction of the form

$$-0''\cdot50-0''\cdot50 \sin \{2^\circ\cdot8[Y-1850\cdot5]\}$$

It will be seen that Mr. Cowell's corrections, when thus supplemented, serve to reduce the tri-annual mean discordances between computation and observation to quantities considerably under a second of arc, which is a great step in advance, though it does not reach the degree of accuracy which should be attained by a satisfactory solution of reducing the discordance to under $\pm0''\cdot50$. The annual means are more discordant, but they are liable to sudden violent fluctuation, due mainly to changes of observers, but partly to meteorological conditions, so that, unless steps are taken to eliminate the effects of these, sudden changes of $\pm0''\cdot50$ may occur in the mean for the year.

A critical examination of the run of the discordances shows clear indication that there yet remain outstanding sensible inequalities of long period which have been omitted by Mr. Cowell. One of about thirty-six years and two of about nine years seem clearly indicated. Increasing all Mr. Cowell's values for the

coefficients of the planetary terms by about a fourth would also sensibly decrease the discordance between computation and observation.

(7) The consideration of the correction of Class III. (§ 3) is postponed for the present, pending further leisure. The value deduced for the "parallactic inequality" requires considerable correction, for the effect of systematic errors he has not taken into account.

(8) In conclusion I must congratulate Mr. Cowell on the degree of success which he has attained in dealing with the long series of Greenwich observations, and especially in showing so clearly that the theoretical values for the perturbations of the Moon by the Sun are in entire harmony with the results of observation. I can appreciate it all the more, as for years I had worked on the same subject; but my results, more detailed and elaborated than Mr. Cowell's, have for years been lying awaiting official publication, and will, I fear, have to wait for several years longer until the revenue of the colony is again normal; so Mr. Cowell's results take precedence, and mine must wait. I could have supplemented Mr. Cowell's data by furnishing the value derived from both observation and theory for most of the terms due to the planetary perturbations, but judged it preferable to keep entirely to the data furnished by Mr. Cowell's successful discussion of the observations.

Discussion of Greenwich Observations of the Sun, 1864–1900.

By P. H. Cowell, M.A.

An observation of a planet from the Earth being the exact counterpart of an observation of the Earth from the planet, it follows that the elements of the Earth's orbit can be obtained from observations of the planets. I hope to analyse the apparent errors of the Greenwich meridian observations of the planets for the years during which Le Verrier's tables were used in the *Nautical Almanac*, and I have already prepared such an analysis for the observations of *Venus*. The corrections to the elements of the Earth's orbit obtained directly from the Sun evidently form a useful check upon the results of the more complex discussion for a planet.

In this paper I only consider the right ascensions of the Sun, and I have only analysed for terms whose arguments are the longitude of the Earth and the difference of longitude of the Earth and *Venus*. In this way corrections to the solar eccentricity and perigee are obtained, and also a correction is obtained to the mass of *Venus*.

The figures to be analysed are given in Table I. The unit is $0^{s}{\cdot}01$; the quantity tabulated is the mean error of right ascension for the month. Each month receives equal weight in the analysis, and the error for 1891 September has been supplied by interpolation.

TABLE I.

Mean Error of Sun's R.A. 1864–1900. *Unit* 0ˢ·01.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1864	− 2	− 4	− 4	+ 3	− 7	− 3	+ 4	+ 3	− 2	+ 3	+ 2	+ 7
1865	− 2	− 1	− 3	+ 3	+ 4	− 1	+ 2	+ 1	+ 10	+ 1	+ 4	+ 8
1866	− 4	0	− 4	− 1	− 7	− 1	0	+ 2	− 2	+ 5	+ 2	− 7
1867	− 8	− 10	+ 1	− 5	− 3	− 7	+ 5	+ 2	0	0	0	+ 3
1868	− 6	− 5	− 6	− 3	− 3	+ 5	+ 2	+ 1	+ 10	+ 5	+ 9	− 3
1869	− 1	− 9	− 13	0	+ 4	− 4	+ 6	+ 3	+ 6	+ 4	+ 3	+ 7
1870	− 3	− 5	− 3	− 2	− 1	− 1	+ 2	+ 1	+ 3	+ 6	+ 3	+ 11
1871	+ 2	0	− 3	− 3	+ 3	+ 3	+ 5	+ 1	+ 4	+ 1	+ 9	+ 3
1872	+ 2	− 3	− 9	− 5	− 4	0	+ 1	+ 1	+ 3	+ 4	+ 4	+ 2
1873	+ 2	+ 3	+ 3	− 3	+ 3	+ 5	− 1	+ 2	+ 7	+ 6	+ 6	+ 9
1874	+ 4	+ 4	+ 3	+ 1	+ 10	+ 6	+ 1	+ 6	+ 5	+ 8	+ 10	+ 9
1875	+ 8	+ 5	+ 3	− 3	+ 3	+ 10	+ 5	+ 2	+ 10	+ 6	+ 11	+ 4
1876	+ 2	+ 2	0	+ 2	+ 7	+ 7	+ 6	+ 7	+ 5	+ 3	+ 7	+ 4
1877	+ 5	0	− 2	− 6	+ 7	+ 5	+ 3	+ 4	− 1	+ 16	+ 8	+ 4
1878	+ 8	+ 2	+ 1	+ 1	− 2	+ 6	+ 9	+ 6	+ 5	+ 5	+ 12	+ 7
1879	+ 4	+ 3	+ 1	+ 4	− 1	+ 2	+ 6	+ 5	+ 3	+ 11	+ 10	+ 10
1880	+ 6	+ 4	− 5	0	+ 3	+ 11	+ 3	+ 6	+ 7	+ 5	+ 12	+ 19
1881	+ 6	+ 6	+ 3	0	+ 4	+ 3	+ 9	+ 5	+ 4	+ 7	+ 8	+ 4
1882	+ 7	+ 2	0	− 1	+ 1	+ 8	+ 2	+ 2	+ 3	+ 4	+ 8	+ 5
1883	+ 7	+ 4	+ 4	+ 2	+ 5	0	+ 6	+ 5	+ 4	+ 5	+ 6	+ 6
1884	+ 3	+ 1	+ 2	+ 2	+ 3	+ 12	+ 2	+ 8	+ 8	+ 6	+ 14	+ 12
1885	+ 9	− 4	+ 3	+ 5	+ 1	+ 7	+ 2	+ 1	+ 9	+ 8	+ 13	+ 7
1886	+ 10	+ 3	+ 2	+ 4	+ 4	+ 7	+ 8	+ 5	+ 9	+ 8	+ 12	+ 7
1887	+ 8	+ 5	+ 2	+ 4	+ 5	+ 4	+ 1	+ 9	+ 6	+ 5	+ 6	+ 8
1888	+ 5	+ 4	+ 6	0	+ 1	+ 3	+ 2	+ 2	+ 7	+ 4	+ 11	+ 7
1889	+ 7	+ 8	+ 5	+ 1	+ 3	+ 10	+ 4	+ 2	+ 9	+ 6	+ 13	+ 9
1890	+ 8	+ 5	+ 2	+ 4	− 3	0	+ 2	+ 8	+ 4	+ 4	+ 13	+ 11
1891	+ 7	+ 3	+ 6	+ 6	+ 5	+ 7	+ 8	+ 14	(+ 7)	+ 8	+ 14	+ 7
1892	+ 7	+ 3	0	+ 7	+ 6	+ 9	+ 10	+ 6	+ 7	+ 12	+ 16	+ 14
1893	+ 13	+ 8	+ 6	+ 10	+ 10	+ 7	+ 10	+ 9	+ 11	+ 7	+ 14	+ 5
1894	+ 12	+ 11	+ 8	+ 6	+ 4	+ 14	+ 13	+ 13	+ 17	+ 12	+ 16	+ 15
1895	+ 15	+ 11	+ 6	+ 7	+ 11	+ 10	+ 13	+ 10	+ 12	+ 12	+ 11	+ 12
1896	+ 10	+ 8	+ 6	+ 8	+ 8	+ 13	+ 9	+ 11	+ 10	+ 14	+ 16	+ 14
1897	+ 9	+ 8	+ 7	+ 4	+ 10	+ 10	+ 14	+ 14	+ 15	+ 17	+ 16	+ 10
1898	+ 12	+ 11	+ 5	+ 7	+ 11	+ 7	+ 8	+ 11	+ 16	+ 17	+ 14	+ 15
1899	+ 16	+ 5	+ 8	+ 8	+ 10	+ 9	+ 12	+ 13	+ 10	+ 17	+ 10	+ 17
1900	+ 11	+ 10	+ 9	+ 6	+ 6	+ 11	+ 8	+ 8	+ 11	+ 14	+ 16	+ 9
Sums	+ 199	+ 98	+ 50	+ 73	+ 121	+ 194	+ 202	+ 209	+ 252	+ 276	+ 359	+ 291

The sum of all the quantities in Table I. is +2324.

The tabular minus observed epoch is therefore $+23^{s}\cdot24 \div 444 = +0^{s}\cdot052 = +0''\cdot78$.

Analysing the sums for the different months and treating E, the Earth's longitude, as 115° for January, 145° for February, and so on, we get

$$(\text{tab.}-\text{obs.})\ +0''\cdot78 - 0''\cdot47 \sin(E-115^\circ) + 0''\cdot00 \cos(E-115^\circ) + (-0''\cdot21 \sin + 0''\cdot04 \cos) 2(E-115^\circ)$$

No appreciable part of the last term will correspond to possible errors of eccentricity or obliquity. The most probable explanation is instrumental error. The preceding term $-0''\cdot47 \sin(E-115^\circ)$ indicates that Le Verrier's eccentricity requires an increase. Here, again, instrumental error probably affects the result. We know, for instance, that there is a diurnal change in the level error whose amplitude is greater in summer than in winter. The effect of this could be roughly estimated, but it seems preferable to analyse the errors as they stand and merely point out that the results are liable to small systematic errors. The extent of the observations (thirty-seven years) is too short to obtain reliable corrections proportional to the time.

The corrections to Le Verrier's longitude in 1882 is therefore

$$-0''\cdot78 + 0''\cdot47 \sin(E-115^\circ)$$
$$= -0''\cdot78 + 0''\cdot46 \sin(E-100^\circ) - 0''\cdot12 \cos(E-100^\circ)$$

Element.	Correction required by Le Verrier in 1882.
Mean longitude	$-0''\cdot78$
Eccentricity	$+0\cdot23$
Coefficient of principal elliptic term in longitude	$+0\cdot46$
Mean anomaly	$-0\cdot12 \div 2e = -3''\cdot6$
Perihelion	$+2\cdot8$

It is interesting to compare these corrections with the differences between Le Verrier's tables and Newcomb's.

Counting T in centuries from 1900·0 we have the following differences, Newcomb–Le Verrier.

Element.	*Formula.* For Differences Newcomb–Le Verrier.	Value in 1882.
Mean longitude ...	$-0''\cdot71 - 0''\cdot82T - 0''\cdot0183T$	$-0''\cdot56$
Perihelion	$+7\cdot8 + 17\cdot26T - 0\cdot19T^2 + 0''\cdot012T^3$	$+4\cdot7$
Principal elliptic coefficient in longitude	$+0\cdot52 + 0\cdot27T + 0\cdot004T^2$	$+0\cdot47$

There is most satisfactory agreement between the eccentricity found in this paper and that used by Newcomb. The mean longitude and perihelion cannot be compared unless allowance is made

(i) For any changes of long-period terms between Le Verrier's tables and Newcomb's.

(ii) For the difference $0''\cdot 8$ between Newcomb's equinox and that used in the Greenwich clock-star list up to and including 1902.

Coming now to the analysis with the heliocentric elongations of *Venus* as argument, an auxiliary angle with nineteen different values

$$180^\circ + \frac{p \times 360^\circ}{19}$$

was employed.

Approximately the value of p increases by unity in each month, that is to say, for each entry of Table I.; but in order to allow for the slight excess of the synodic period of *Venus* over nineteen Julian months, the value $p = 4$ is assigned to both 1868 January and February; $p = 14$ to both 1874 November and December; $p = 5$ to both 1885 September and October; $p = 15$ to 1894 July and August. We thus obtain

TABLE II.

V–E.	p.	Sum of Errors.	No.
198°·9	1	+106	23
217·9	2	+118	23
236·8	3	+104	23
255·8	4	+104	24
274·7	5	+138	24
293·7	6	+109	23
312·6	7	+121	23
331·6	8	+125	23
350·5	9	+130	23
9·5	10	+124	23
28·4	11	+143	23
47·4	12	+111	23
66·3	13	+127	24
85·3	14	+149	25
104·2	15	+128	25
123·2	16	+119	23
142·1	17	+ 97	23
161·1	18	+133	23
180·0	19	+138	23

Analysing in the usual way we have

$$(\text{tab.}-\text{obs.}) \quad +0''\cdot 03 \sin(V-E) + 0''\cdot 00 \sin 2(V-E)$$

Newcomb, using a mass of *Venus* 1 : 408000, obtains terms in the Earth's longitude

$$-4''\cdot 838 \sin(V-E) + 5''\cdot 526 \sin 2(V-E)$$

Le Verrier, using a mass of *Venus* 1 : 401847, in his theory obtains

$$-4''\cdot 913 \sin(V-E) + 5''\cdot 613 \sin 2(V-E)$$

but in his tables he uses a mass (*Annales de l'Obs. de Paris*, vol. iv. p. 34) 1 : 400246 (p. 102) with inequalities

$$-4''\cdot 93 \sin(V-E) + 5''\cdot 63 \sin 2(V-E)$$

To these terms the apparent corrections just obtained are

$$-0''\cdot 03 \sin(V-E) + 0''\cdot 00 \sin 2(V-E)$$

For the mass of *Venus* we therefore have

from the term in	V − E	1·006 to	400246
„ „	2(V − E)	1·000 „	400246
	Mean	1·003 to	400246.

Newcomb, in his provisional theory (*Astron. Constants*, pp. 7, 8), uses 1 : 401847, and on p. 22, last six lines, he obtains a correction + ·007 from the Greenwich observations 1867–1892, in close accordance with the result of this paper. The present paper, however, supplements Newcomb's calculations by considering the two principal terms separately instead of all the terms together.

Professor Newcomb, however, swamps the result obtained from recent Greenwich observations by introducing additional material of decidedly inferior value, and on pp. 101–2 he reaches the result 1 − ·0119 : 401847, and in his tables of the Sun he uses 1 : 408000, as stated above.

This latter value would imply that the two coefficients as obtained from the thirty-seven years 1864 to 1900 are respectively 0″·12 and 0″·10 in error. I do not believe that such errors are possible in the case of terms of short periods different from the periods of possible instrumental errors; certainly in my analyses of the errors of the Moon I found no such discordances in cases where comparison could be made with well-determined theoretical values.

Moreover, in the older observations I did find large discordances in the case of the Moon, and I can easily believe that they may also exist in the case of the Sun. It must be remembered that the older observations of the Sun and Moon have not been

re-reduced with the same care that has lately been bestowed on several of the earlier star catalogues. I consider therefore that Professor Newcomb has given excessive weight to his other material, and that it would have been better to leave Le Verrier's mass of *Venus* unaltered.

Reciprocal of Mass of *Venus*.

Le Verrier	400×10^3
Newcomb	408×10^3
Present paper	399×10^3

Discussion of Greenwich Observations of Venus, 1869–1900. By P. H. Cowell, M.A.

The observations under examination are divided into four periods of analysis of eight years each. Eight years is equivalent to thirteen revolutions of *Venus*, or five synodic periods. For each period of analysis corrections to the mean longitude, eccentricity, and perihelion of both the Earth and *Venus* are obtained. A correction of about 3″ to Le Verrier's centennial motion of *Venus* is distinctly indicated, but a period of thirty-two years is naturally too short to obtain reliable corrections proportional to the time. I have therefore merely taken means for the four periods of analysis, and thus obtained corrections applicable to Le Verrier's elements for 1885·0.

The peculiarity of my analysis is that it contains no simultaneous equations, a feature which I believe will be appreciated by readers of Le Verrier, vol. vi. pp. 58–70, or Newcomb, *Astronomical Constants*, p. 92. This has been achieved by forcing symmetry into the distribution of observations by giving enhanced weight, whenever necessary, to isolated observations. The process no doubt slightly diminishes the weight of the results as compared with an ideal method, but, as I shall now show, it involves a considerable increase of accuracy as compared with the more laborious methods just referred to. In Newcomb's *Astronomical Constants*, p. 57, we read : "In dealing with so extensive a system of unknown quantities it is impracticable to investigate the dependence of each upon all the others." Now it is just this dependence, which Newcomb found it impracticable to investigate, which is brought out in the present paper. And the investigation is by no means unnecessary ; for I shall show that the corrections to the eccentricity and perihelion of the Earth are determined by a vector quantity whose components are $y+z$, $y'+z'$. A similar statement holds for *Venus* with components $y+2z$, $y'+2z'$. It also appears that y, y' are quantities that can only be determined with 10 per cent. of the weight

of z, z'. Now when the dependence of each of the unknown quantities upon the others is not investigated, the errors of *Venus* are determined with no greater weight than y, y'. In the present analysis it is practicable to adopt the value of the vector $y+z$, $y'+z'$ directly from the observations of the Sun, and to pass to *Venus* by adding the well-determined vector z, z', thus obtaining $y+2z$, $y'+2z'$. Owing to the enormous number of observations available, there is no great difference between the numerical results of the two processes.

It is necessary to exhibit results by resolving into corrections to eccentricity and perihelion. This can be done, however, after the analysis; for the purposes of analysis it is preferable to resolve towards and at right angles to the direction of conjunction. During any period of analysis therefore, V, E will denote the mean longitudes of *Venus* and Earth measured from the common longitude of the third (or middle of five) inferior conjunction.

Period of Analysis.	Longitude of Third Inferior Conjunction.	Date.
1869–1876	222°·5	1873 May 4
1877–1884	220·2	1881 May 1
1885–1892	217·9	1889 April 29
1893–1900	215·6	1897 April 26

The variables $x\ x'$, $y\ y'$, $z\ z'$ are defined thus: the corrections to the longitudes of *Venus* and Earth are

$$\delta\mathrm{V} = x + x' + 2(y+2z)\sin\mathrm{V} + 2(y'+2z')\cos\mathrm{V}$$
$$\delta\mathrm{E} = \qquad x' + 2a(y+z)\sin\mathrm{E} + 2a(y'+z')\cos\mathrm{E}$$

then, in order to conform to Kepler's laws, it is necessary to put for the variations of the radii vectores

$$\delta r' = -a(y+2z)\cos\mathrm{V} + a(y'+2z')\sin\mathrm{V}$$
$$\delta r = -a(y+z)\cos\mathrm{E} + a(y'+z')\sin\mathrm{E}$$

where a = ratio of mean distances = 0·7233.

It will be noticed that if y, y' alone are different from zero the displacements of the two planets are equal and parallel at all conjunctions; the geocentric displacement of *Venus* is therefore zero; y, y' therefore must be determined from observations remote from conjunction; the small weights with which they are determined may therefore be anticipated.

In forming the equations of condition the utmost simplicity is desirable. Complex equations are laborious, both to form and to solve. At the worst, the modifications introduced for the sake of simplicity will only cause the solution obtained to be an approximation to, instead of identical with, the solution of accurate equations. The approximate solution could be carried accurately into the tabular places, and fresh residuals formed,

Period I. 1869–1876. Unit $0^s\cdot01$.
Longitude at middle inferior conjunction = $222^\circ\cdot5$.
Date 1873 May 4.

Mean Error of Right Ascension of Venus.

V−E.	0.	1.	2.	3.	4.	5.	Sum.
180°	...	+19	(+12)	+ 2	(+ 8)	(+ 6)	+ 47
195	...	+ 2	+ 9	+ 9	+ 7	− 3	+ 24
210	...	+13	(+11)	+ 6	+10	+ 3	+ 43
225	...	+29	+13	+14	+16	(+ 5)	+ 77
240	...	− 8	+ 9	+22	+16	(+ 6)	+ 45
255	...	+ 7	+21	(+15)	+ 7	+10	+ 60
270	...	+10	+ 2	+13	+12	+ 9	+ 46
285	...	+ 5	+19	+15	+16	+14	+ 69
300	...	+ 1	(+10)	+ 8	+ 5	+18	+ 42
315	...	− 4	+10	+ 6	+22	+23	+ 57
330	...	0	+10	+ 8	+11	+22	+ 51
345	...	− 7	+ 8	+ 8	+ 8	+15	+ 32
0	...	−13	−18	− 2	− 6	− 6	− 45
15	...	−10	− 9	− 4	(− 6)	+ 5	− 24
30	...	− 4	− 6	+ 5	− 8	− 4	− 17
45	...	− 2	− 1	− 3	+ 2	+10	+ 6
60	...	0	+ 2	+ 3	+ 4	+ 7	+ 16
75	...	+ 4	+ 3	+ 4	+ 4	+ 9	+ 24
90	...	+ 5	− 1	+10	+12	+ 3	+ 29
105	− 9	+12	− 5	+ 8	+ 1	...	+ 7
120	− 8	+ 7	+ 1	+ 3	+15	...	+ 18
135	+ 2	+ 7	+ 6	+15	+ 5	...	+ 35
150	(+ 1)	+14	+ 9	0	+ 8	...	+ 32
165	0	+14	+16	+10	+10	...	+ 50
				General Sum		... ...	+724

and a second approximation obtained with the simple equations of condition. The simplifications that I am about to introduce, however, do not appear to prevent the solutions from being accurate to within 5 or 10 per cent., and the imperfections of the observations themselves probably preclude a higher degree of accuracy. The errors of Le Verrier's tables are in fact so small that 5 per cent. of their amount is too small a quantity to determine. The simplifications are as follows:

In forming the variation of geocentric longitude in terms of the errors of heliocentric coordinates, the orbits are supposed circular and co-planar, the mean motions during one period of analysis are taken as accurately in the ratio 13 : 8, and an error

Period II. 1877–1884. Unit $0^s.01$.
Longitude at middle inferior conjunction = $220^\circ.2$.
Date 1881 May 1.

Mean Error of Right Ascension of Venus.

V–E.	0.	1.	2.	3.	4.	5.	Sum.
180°	...	(+ 2)	(0)	(+10)	(0)	(+ 6)	+ 18
195	...	+ 6	0	(+10)	− 1	(+ 6)	+ 21
210	...	+17	(+ 3)	+ 5	+10	+ 6	+ 41
225	...	+ 6	+ 7	+18	+22	+12	+ 65
240	...	+ 2	+ 8	+ 2	+20	(+ 6)	+ 38
255	...	+ 7	+16	+15	+ 8	+ 2	+ 48
270	...	+11	+14	+ 8	+ 4	+ 5	+ 42
285	...	+ 2	+ 6	+ 5	+ 5	+17	+ 35
300	...	+ 6	+ 4	+ 8	+12	+ 6	+ 36
315	...	− 1	+17	(+ 9)	− 1	+11	+ 35
330	...	+ 5	+10	+11	+ 5	+ 4	+ 35
345	...	− 8	+13	+ 3	−29	+13	− 8
0	...	− 2	+ 3	− 6	−55	+ 3	− 57
15	...	− 6	− 5	− 4	−34	+ 3	− 46
30	...	− 5	+ 1	+ 6	− 7	+ 6	+ 1
45	...	− 2	+ 2	+11	− 4	+ 7	+ 14
60	...	+ 8	+ 6	+13	+ 3	+ 5	+ 35
75	...	+ 7	+22	+ 7	+ 7	+15	+ 58
90	...	+ 1	+ 1	+ 9	+ 6	+ 9	+ 26
105	(+ 1)	+ 7	− 6	+ 6	+ 5	...	+ 13
120	0	+ 2	+12	+ 1	+ 8	...	+ 23
135	−18	+ 2	(+10)	0	+13	...	+ 7
150	− 2	+ 5	+ 8	− 6	+ 5	...	+ 10
165	(0)	0	+15	(0)	+ 7	...	+ 22
				General Sum		... ...	+512

of right ascension is treated as equivalent to an error of longitude.

We therefore put $V = 13\theta$ $E = 8\theta$ $V-E = \phi = 5\theta$.

For the geocentric distance Δ we have $\Delta^2 = 1 - 2a\cos\phi + a^2$.

For the variation of geocentric longitude

$$d\lambda = \frac{a}{\Delta^2}\left\{\left(-\frac{dr'}{a}+dr\right)\sin(V-E)+\left(adV+\frac{dE}{a}\right)\right.$$
$$\left.-(dV+dE)\cos(V-E)\right\}$$

whence substituting the values of dr' &c. in terms of x, x'...

Period III. 1885–1892. Unit $0^s{\cdot}01$.
Longitude at middle inferior conjunction $= 217^\circ{\cdot}9$.
Date 1899 April 29.

Mean Error of Right Ascension of Venus.

V–E.	0.	1	2.	3.	4.	5.	Sum.
180°	...	+10	(+ 6)	(+10)	(+ 6)	(+ 7)	+ 39
195	...	+12	(+ 8)	+ 8	+ 6	+ 3	+ 37
210	...	+14	+10	−10	+ 5	+21	+ 40
225	...	+11	+14	+ 7	+12	+ 9	+ 53
240	...	+14	+12	+21	+11	+13	+ 71
255	...	+14	+17	+ 8	+ 5	+18	+ 62
270	...	+ 8	+12	+11	+ 5	+ 8	+ 44
285	...	+16	+ 9	+ 7	+ 4	+ 4	+ 40
300	...	+ 3	+11	+ 5	− 3	+10	+ 26
315	...	+ 4	+21	+ 2	+ 7	+ 8	+ 42
330	...	+ 4	+ 8	+15	− 4	+10	+ 33
345	...	0	− 9	+ 8	−23	+15	− 9
0	...	− 6	−30	−11	−55	+ 2	−100
15	...	− 7	−23	+ 1	−20	+15	− 34
30	...	− 1	−10	+10	− 6	+16	+ 9
45	...	− 1	0	+ 6	+ 2	+ 8	+ 15
60	...	+ 4	0	+ 9	+ 9	+20	+ 42
75	...	+ 8	+11	+14	− 9	(+15)	+ 39
90	...	+19	+ 9	+17	+ 4	+14	+ 63
105	(+ 6)	+14	+14	+ 8	+10	...	+ 52
120	(+ 3)	+ 4	+ 5	+12	+12	...	+ 36
135	+ 1	+ 8	−10	+11	+ 8	...	+ 18
150	− 3	+ 3	+14	+ 6	+10	...	+ 30
165	− 3	+ 5	+11	+ 8	(+ 8)	...	+ 29
				General Sum	...	...	+677

$d\lambda = ax + a'x + by + b'y' + cz + c'z' = \epsilon =$ tab.–obs. error of R.A.

where $a = \frac{a}{\Delta^2}\{a - \cos 5\theta\}$

$$a' = 1$$

$$b = \frac{a}{\Delta^2}\sin 5\theta\{-\cos 13\theta + a\cos 8\theta\}$$

$$b' = \frac{a}{\Delta^2}\sin 5\theta\{\sin 13\theta - a\sin 8\theta\}$$

Period IV. 1893–1900. Unit $0^{s}\cdot01$.
Longitude at middle inferior conjunction = $215^{\circ}\cdot6$.
Date 1897 April 26.

Mean Error of Right Ascension of Venus.

V–E.	0.	1.	2.	3.	4.	5.	Sum.
180°	...	(+13)	(+13)	(+15)	+18	(+15)	+ 74
195	...	+16	(+16)	+10	+ 9	+17	+ 68
210	...	+16	+19	+ 9	+ 7	+16	+ 67
225	...	+15	+12	+ 4	+16	+12	+ 59
240	...	+ 4	+14	+10	+25	+25	+ 78
255	...	+13	+15	+12	+ 7	+ 9	+ 56
270	...	+11	+17	+12	+ 2	+14	+ 56
285	...	+10	+13	+ 8	+ 6	+10	+ 47
300	...	+10	+11	(+ 7)	+10	+ 7	+ 45
315	...	+ 8	+12	+ 6	+11	+11	+ 48
330	...	− 2	+11	+ 8	−10	+12	+ 19
345	...	−12	+ 6	+ 6	−16	+16	0
0	...	−23	−14	0	35	+18	− 54
15	...	−14	0	+ 1	−20	+13	− 20
30	...	− 6	− 1	+16	− 4	+15	+ 20
45	...	− 6	+13	+19	+ 5	+14	+ 45
60	...	+ 7	+18	+21	+15	+17	+ 78
75	...	+20	+ 2	+19	+ 5	+20	+ 66
90	...	+21	+12	+12	+ 8	+11	+ 64
105	...	+20	+ 5	+13	+11	+ 7	+ 56
120	(+10)	+11	+ 6	+ 8	+ 9	...	+ 44
135	+ 5	+10	+12	+12	+17	...	+ 56
150	+ 2	+13	+10	+14	+11	...	+ 50
165	+11	+11	+15	−11	+13	...	+ 39
				General Sum		... ...	1061

$$c = \frac{a}{\Delta^2}\left[-\sin 18\theta + \tfrac{5}{2}a \sin 13\theta - \sin 8\theta - \tfrac{1}{2}a \sin 3\theta\right]$$

$$c' = \frac{a}{\Delta^2}\left[-\cos 18\theta + \tfrac{5}{2}a \cos 13\theta - \cos 8\theta - \tfrac{1}{2}a \cos 3\theta\right]$$

The mean values of aa', ab, ab' are all zero. Therefore, when symmetry has been imported into the observations by suitably manipulating the weights, the normal equations are

$$x = \Sigma a\epsilon \div \Sigma a^2 \text{ with a weight } \Sigma a^2 \text{ \&c.}$$

We now form tables from the preceding formulæ.

TABLE I.

Value of a. *Unit* =0·01. *Mean Square* =0·55.

V–E.	*a.*
180	+ 42
195	+ 42
210	+ 41
225	+ 41
240	+ 39
255	+ 37
270	+ 34
285	+ 29
300	+ 20
315	+ 2
330	− 38
345	−140
0	−261
15	−140
30	− 38
45	+ 2
60	+ 20
75	+ 29
90	+ 34
105	+ 37
120	+ 39
135	+ 41
150	+ 41
165	+ 42

The quantities in Tables I.–VI. are set down to two places of decimals, but they are subsequently used to one place only.

TABLE II.

$a' = 1{\cdot}0.$ *Mean Square* = 1·0.

$$\frac{1-a^2}{\Delta^2} = 1 + 2\Sigma^\infty{}_1\, a^j \cos j\phi$$

$$\frac{(1-a^2)^3}{\Delta^4} = 1 + a^2 + 2\Sigma^\infty{}_1\, a^j \cos j\phi[(j+1)-(j-1)a^2]$$

whence the following mean values may be obtained of

$$\frac{1-a^2}{\Delta^2} = 1 \qquad \frac{(1-a^2)\cos 2\phi}{\Delta^2} = a^2$$

$$\frac{(1-a^2)\cos\phi}{\Delta^2} = a \qquad \frac{(1-a^2)\cos^2\phi}{\Delta^2} = \tfrac{1}{2}(1+a^2)$$

TABLE III.

Value of b. *Unit* 0·01. *Mean Square* = 0·13.

V–E.	1.	2.	3.	4.	0 or 5.
180	0	0	0	0	0
195	−9	+4	+3	−8	+10
210	−9	−4	+16	−22	+19
225	+5	−22	+31	−29	+15
240	+28	−41	+39	−21	−4
255	+49	−48	+28	+2	−32
270	+55	−34	0	+34	−55
285	+40	−2	−37	+62	−63
300	+3	+39	−65	+67	−43
315	−41	+68	−69	+44	−2
330	−68	+65	−37	−5	+45
345	−42	+15	+17	−44	+53
0	0	0	0	0	0
15	−53	+44	−17	−15	+42
30	−45	+5	+37	−65	+68
45	+2	−44	+69	−68	+41
60	+43	−67	+65	−39	−3
75	+63	−62	+37	+2	−40
90	+55	−34	0	+34	−55
105	+32	−2	−28	+48	−49
120	+4	+21	−39	+41	−28
135	−15	+29	−31	+22	−5
150	−19	+22	−16	+4	+9
165	−10	+8	−3	−4	+9

$$\frac{\sin^2\phi}{\Delta^2} = \frac{1}{2} \qquad \frac{(1-a^2)^3\cos^2\phi}{\Delta^4} = \tfrac{1}{2}(1+4a^2-a^4)$$

$$\frac{(1-a^2)^3}{\Delta^4} = 1+a^2 \qquad \frac{(1-a^2)\sin^2\phi}{\Delta^4} = \frac{1}{2}$$

$$\frac{(1-a^2)^3\cos\phi}{\Delta^4} = 2a \qquad \frac{(1-a^2)^3\cos 3\phi}{\Delta^4} = \frac{a}{2}(3+2a^2-a^4)$$

$$\frac{(1-a^2)^3\cos 2\phi}{\Delta^4} = a^2(3-a^2) \qquad \frac{(1-a^2)\cos\phi\sin^2\phi}{\Delta^4} = \frac{a}{2}$$

$$\frac{(1-a^2)^3\cos 3\phi}{\Delta^4} = a^3(4-2a^2)$$

Considerations of symmetry will show that the mean values of twelve out of the fifteen quantities aa' &c. are zero.

The above formulæ will readily show that aa', bc, $b'c'$ also take zero mean values.

TABLE IV.

Value of b'. *Unit* 0·01. *Mean Square* = 0·13.

V−E.	1.	2.	3.	4.	9 or 5.
180	0	0	0	0	0
195	+6	−10	+10	−6	+1
210	+20	−21	+15	−2	−11
225	+32	−23	+5	+14	−28
240	+32	−9	−17	+36	−42
255	+14	+18	−43	+51	−40
270	−18	+47	−58	+47	−18
285	−52	+65	−54	+22	+18
300	−70	+58	−24	−19	+55
315	−59	+24	+21	−57	+72
330	−17	−26	+59	−70	+53
345	+32	−51	+50	−30	−1
0	0	0	0	0	0
15	−1	−30	+50	−51	+32
30	+53	−70	+59	−26	−17
45	+72	−57	+21	+24	−59
60	+55	−19	−24	+58	−70
75	+18	+22	−54	+65	−52
90	−18	+47	−58	+47	−18
105	−40	+51	−43	+18	+14
120	−42	+36	−17	−9	+32
135	−28	+14	+5	−23	+32
150	−11	−2	+15	−21	+20
165	+1	−6	+10	−10	+6

We also obtain

mean value of $a^2 = \frac{1}{2}\,\frac{\alpha^2}{1-\alpha^2}$

" " $a'^2 = 1$

" " b^2 or $b'^2 = \frac{1}{4}\alpha^2$

" " c^2 or $c'^2 = \frac{\alpha^2(1+\frac{1}{4}\alpha^2)}{1-\alpha^2}$

The observations are divided into groups of 24·33006 days each; the centre of each group corresponds to an exact multiple of 15° in the mean heliocentric elongation. There are 120 groups in each period of analysis. The mean error of right ascension is given in the following tables. Whenever an error is enclosed in brackets, it implies there were no observations in the corresponding group, but an error has been interpolated from

TABLE V.

Value of c. *Unit* 0·01. *Mean Square* = 1·24.

V−E.	1.	2.	3.	4.	0 or 5.
180	0	+ 49	− 80	+ 80	− 49
195	− 57	+ 83	− 78	+ 42	+ 9
210	− 87	+ 77	− 37	− 17	+ 65
225	− 77	+ 32	+ 24	− 72	+ 92
240	− 30	− 30	+ 78	− 97	+ 78
255	+ 33	− 82	+ 101	− 81	+ 30
270	+ 83	− 103	+ 83	− 32	− 32
285	+ 101	− 86	+ 37	+ 26	− 79
300	+ 86	− 46	− 11	+ 64	− 92
315	+ 60	− 21	− 27	+ 64	− 77
330	+ 86	− 59	+ 10	+ 43	− 80
345	+ 271	− 216	+ 78	+ 90	− 224
0	+ 497	− 308	0	+ 308	− 497
15	+ 224	− 90	− 78	+ 216	− 271
30	+ 80	− 43	− 10	+ 59	− 86
45	+ 77	− 64	+ 27	+ 21	− 60
60	+ 92	− 64	+ 11	+ 46	− 86
75	+ 79	− 26	− 37	+ 86	− 101
90	+ 32	+ 32	− 83	+ 103	− 83
105	− 30	+ 81	− 101	+ 82	− 33
120	− 78	+ 97	− 78	+ 30	+ 30
135	− 92	+ 72	− 24	− 32	+ 77
150	− 65	+ 17	+ 37	− 77	+ 87
165	− 9	− 42	+ 78	− 83	+ 57

neighbouring observations. It will be seen that bracketed errors are most frequent at superior conjunction, but seldom occur elsewhere.

The analysis of the errors consists simply in multiplying each entry by the corresponding entry of Tables I.–VI. and dividing by 120 times the mean square of the factor.

For example, Period I. 1869–1876, to find x.

The formula is $x = \Sigma a\epsilon \div \Sigma a^2$, where ϵ denotes an entry in the table of Period I., and the values of a are given in Table I. As the value of a is a function of V−E only, we naturally proceed to add horizontally (the sums are exhibited in the extreme right-hand column).

Similarly $x' = \Sigma a'\epsilon \div \Sigma a'^2 = \dfrac{\Sigma\epsilon}{120}$, since $a' = 1$. The value of $\Sigma\epsilon$ is exhibited in the right-hand bottom corner.

TABLE VI.

Value of c'. *Unit* 0·01. *Mean Square* = 1·24.

V–E.	1.	2.	3.	4.	0 or 5.
180	– 84	+ 68	– 26	– 26	+ 68
195	– 63	+ 18	+ 34	– 74	+ 85
210	– 10	– 43	+ 80	– 86	+ 59
225	+ 51	– 86	+ 89	– 57	+ 4
240	+ 92	– 92	+ 57	0	– 57
255	+ 95	– 58	– 2	+ 61	– 96
270	+ 61	0	– 61	+ 98	– 98
285	+ 6	+ 55	– 94	+ 98	– 64
300	– 39	+ 82	– 93	+ 69	– 19
315	– 48	+ 74	– 72	+ 43	+ 3
330	– 18	+ 65	– 88	+ 77	– 37
345	– 6	+166	–261	+256	–153
0	–161	+423	–523	+423	–161
15	–153	+256	–261	+166	– 6
30	– 37	+ 77	– 88	+ 65	– 18
45	+ 3	+ 43	– 72	+ 74	– 48
60	– 19	+ 69	– 93	+ 82	– 39
75	– 64	+ 98	– 94	+ 55	+ 6
90	– 98	+ 98	– 61	0	+ 61
105	– 96	+ 61	– 2	– 58	+ 95
120	– 57	0	+ 57	– 92	+ 92
135	+ 4	– 57	+ 89	– 86	+ 51
150	+ 59	– 86	+ 80	– 43	– 10
165	+ 85	– 74	+ 34	+ 18	– 63

The details of the calculation of y, y', z, z' are not exhibited: they consist merely in 120 multiplications. The factors used are given in Tables III., IV., V., and VI., but one less significant figure is employed.

Multiplying by 15, to transform to seconds of arc, we thus get the following table of results:

Period.	Long. of Conjunction.	Date.	Wt. 55. x	Wt. 100. x'	Wt. 13. y	Wt. 13. y'	Wt. 124. z	Wt. 124. z'
			$''$	$''$	$''$	$''$	$''$	$''$
I.	222·5	1873 May 4	+0·75	+0·90	+0·44	0·00	–0·23	–0·15
II.	220·2	1881 1	+0·90	+0·64	+0·55	+0·18	–0·57	–0·41
III.	217·9	1889 Apr. 29	+1·27	+0·84	+0·54	+0·15	–0·33	–0·61
IV.	215·6	1897 26	+1·15	+1·32	+0·84	–0·22	–0·60	–0·42
Means	219·0		+1·02	+0·92	+0·59	+0·03	–0·43	–0·40

This completes the analysis: it is impossible to get reliable terms proportional to the time from thirty-two years' observations, but the run in the values of $x+x'$, the correction to the mean longitude of *Venus*, approximately confirms Newcomb's diminution by $3''$ of Le Verrier's centennial motion.

The mean results apply to the date 1885·0.

From the Sun observations I obtained as a correction to the Sun's longitude

$$\text{(tab.—obs.)} \quad +0''{\cdot}78 - 0''{\cdot}47 \sin(E - 115^\circ)$$
$$\text{or} \quad +0{\cdot}78 - 0{\cdot}46 \cos(E - 219) + 0''{\cdot}11 \sin(E - 219^\circ)$$

Dividing the last two coefficients by $2a = 1{\cdot}447$, we have from the Sun observations and in the notation of this paper

$$x' = +0''{\cdot}78 \quad y+z = +0''{\cdot}08 \quad y'+z' = -0''{\cdot}31 \quad \ldots \quad \text{(i.)}$$

These values are entitled to far greater weight than the corrections to the solar elements obtained from *Venus*

$$x' = +0''{\cdot}92 \quad y+z = +0''{\cdot}16 \quad y'+z' = -0''{\cdot}37 \quad \ldots \quad \text{(ii.)}$$

It will be seen, however, that the accordance is most satisfactory.

In passing to the corrections for *Venus* I use values (i.) and reject values (ii.) for x', $y+z$, $y'+z'$. This makes it possible to get corrections for *Venus* independently of the values of y, y'.

We thus have for *Venus*

$$x+x' = +1''{\cdot}80 \quad y+2z = -0''{\cdot}35 \quad y'+2z' = -0''{\cdot}71$$

or Le Verrier's longitude of *Venus* requires corrections in 1885·0,

$$-1''{\cdot}80 + 2 \times 0''{\cdot}35 \sin(V - 219^\circ) + 2 \times 0''{\cdot}71 \cos(V - 219^\circ)$$
$$= -1{\cdot}80 + 2 \times 0{\cdot}72 \sin(V - 130) - 2 \times 0{\cdot}34 \cos(V - 130),$$

on resolving in the direction of the perihelion of *Venus*.

Hence corrections required by Le Verrier's elements in 1885·0 are

Element.	Correction required by Le Verrier in 1885·0.
Mean longitude	$-1''{\cdot}80$
Eccentricity	$+0{\cdot}72$
Coefficient of principal elliptic term in longitude	$+1{\cdot}44$
Mean anomaly	$-0{\cdot}34 \div e = -50''$
Perihelion	$+48''$

It is interesting to compare these corrections with the differences between Le Verrier's tables and Newcomb's.

Counting T in centuries from 1900·0 we have the following differences, Newcomb–Le Verrier :

Formula.

Element.	For Difference Newcomb–Le Verrier.	Value in 1885·0.
	$''$ $''$ $''$	$''$
Mean longitude ...	$-1.74-3.29T-0.0141T^2$	-1.25
Perihelion	$+83.9+128.66T+2.415T^2$	$+64.6$
Principal elliptic coefficient in longitude	$+1.79+2.518T-0.015T^2$	$+1.41$

There is thus most satisfactory agreement between the eccentricity found in this paper and that used by Newcomb. The mean longitude and perihelion cannot be compared unless allowance is made

(i.) For any changes of long-period terms between Le Verrier's tables and Newcomb's.

(ii.) For the difference $0''.8$ between Newcomb's equinox and that used in the Greenwich clock-star list up to and including 1902.

It will be seen that (ii.) approximately explains the difference between Newcomb's correction to the mean longitude and that obtained in this paper.

It will be seen that the analyses of this paper are unaffected by the following alterations which involve odd functions of the elongation only in the geocentric places :

(i.) A change in Le Verrier's mass of the Earth + Moon which will introduce corrections varying as sin (V – E), sin 2(V – E), &c. with the tabular geocentric places.

(ii.) A change in the tabular semidiameter and Stone's empirical alteration thereof, which, as it takes opposite signs before and after conjunction, can presumably be expanded in a form

$$\pm\mu + a_1 \sin(V-E) + a_2 \sin 2(V-E) + \ . \ . \ .$$

I have not yet examined how far it is possible to disentangle errors of defective illumination from errors due to Le Verrier's mass of the Earth + Moon, and so obtain a determination of this mass ; but it is fairly obvious that no such determination can compete with the value resulting from pendulum experiments.

It is sufficient for the purposes of this paper to point out that the mean value of the product of either of the above two corrections by any of the six quantities a, a', b, b', c, c' is by symmetry zero.

Comparison of Carrington's Circumpolar Catalogue with the Greenwich-Groombridge System. By W. G. Thackeray.

(*Communicated by the Astronomer Royal.*)

The forthcoming Greenwich Catalogue for 1900 will consist of two parts : Part I., Fundamental and Zodiacal Stars ; Part II., Astrographic Reference Stars. This latter part consists of some 10,000 circumpolar stars within 26° of the pole. As the Carrington Catalogue affords the only data from which the proper motion of the majority of the stars within 9° of the pole can be determined, it is necessary to investigate its systematic errors, and for this purpose a comparison has been made with those stars which are common to it and the Groombridge-Greenwich system. There are ninety-four stars available, which have been grouped in degrees according to the Carrington Catalogue place.

The Carrington Catalogue contains 3735 stars, extending from 0° to 9° polar distance. The positions are based on instrumental errors derived from twenty special polars the places of which were finally determined by reference to double transits of *Polaris* and *Ursæ Minoris* (Introduction, pp. 13, 22–35). Four or more of these stars—two above pole and two below pole whenever possible—were taken for the determination of the meridian error and of the polar point (p. 15). The circle, which was made to turn on its collar and which was divided by Troughton & Simms's well known engine, was not provided with any means for the determination of errors of division. As the circle was not moved by Carrington during the period covered by his catalogue observations the division errors are the same throughout and necessarily remain uncorrected (p. 16). There were four fixed microscopes with which to read the circle, a vertical and horizontal pair, but after the first year only the horizontal pair were used (p. 7). The catalogue stars were observed and arranged in three sub-zones.

The first	sub-zone	from	45′	to	4°	of N.P.D.
,, second	,,	,,	4°	,,	7°	,,
,, third	,,	,,	7	,,	9	,,

The places of the stars in the first sub-zone depend on practically an equal number of observations above and below pole. The stars in the second sub-zone for 4° to 6° are mostly observed for the first three hours either one above or two below, or two above and one below. For 7°, with few exceptions, and for the third sub-zone, stars are observed entirely above pole.

The results of the comparison taken as corrections to Carrington's Catalogue place given in the following tables are :—

	0°.	1°.	2°.	3°.	4°.	5°.	6°.	7°.	8°.	9°.
	s	s	s	s	s	s	s	s	s	s
R.A.	+0·7	+0·4	−0·3	−0·1	+0·2	−0·4	−0·3	−0·2	−0·4	0·0
	″	″	″	″	″	″	″	″	″	″
N.P.D.	−0·3	+0·3	+0·5	+0·6	+0·9	+1·0	+1·1	+1·2	+1·4	+0·1
No. of stars	1	7	4	11	10	15	11	11	17	7

It has been decided to apply a systematic correction of $-0^s\cdot3$ to the right ascension of stars of 5° to 9° N.P.D. The corrections to the north polar distances which are regular and systematic seem to point to the influence of uncorrected division errors, and this is confirmed from further comparing the observations above with those below pole, which can be easily done from the ledgers in the sub-zones where the observations below the pole are marked with an asterisk (*) and the difference from the adopted catalogue place given for each observation.

The following is the excess of N.P.D. above pole :—

0°.	1°.	2°.	3°.	4°.	5°.	6°.	7°.
″	″	″	″	″	″	″	″
−0·1	−0·3	−0·4	−1·0	−1·0	−1·3	−1·4	−1·6
12	122	178	302	104	95	121	6

The stars at 4° are made up of thirty-nine stars in the first sub-zone and sixty-five in the second sub-zone.

The following are the systematic corrections to be adopted for the north polar distances.

For the second sub-zone in which the observations below pole are not symmetrical and are most numerous at 0^h–3^h, in order to obviate systematic differences it will be first necessary to bring into line the catalogue place of all stars which have S.P. observations by applying a correction to all S.P. observations as follows :—

N.P.D.	Correction.
°	″
4	−1·0
5	−1·3
6, 7°	−1·4

Then, as the first sub-zone contains an equal number of observations above and below pole, and in the third sub-zone all the observations are above pole, the following are adopted as the corrections from the catalogue comparison :—

N.P.D.	Correction.	N.P.D.	Correction.
° °	″	°	″
0, 1	+0·3	6	+1·1
2	+0·5	7	+1·2
3	+0·6	8	+1·2
4	+0·9	9	+1·2
5	+1·0		

Comparison between Carrington and Groombridge-Greenwich in R.A. for each 1° of N.P.D.

	0°.		1°.		2°.		3°.		4°.		5°.		6°.		7°.		8°.		9°.	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
	0·7*			0·2*	0·3			1·4	0·9			0·5		0·2	0·0			0·2		0·1
			0·3*			0·6*		0·6	0·2			0·7		0·9	0·3		0·3			0·5
				0·1*		1·0	0·1			0·3*	0·5		0·1		0·1			0·2		0·5
				0·2*		0·0*	0·3*		0·6*			0·4		1·1		0·1	0·1		0·2	
			0·7		...			0·5*	0·0			0·8		1·2		1·4		0·2		0·2
			0·6*		...		0·4		0·8			0·6	0·1			1·0		0·6	0·5	
			1·5		...			0·1	0·5			0·4	0·4			0·2		0·3	0·4	
			...		...		0·1*			0·6		0·3		1·1		0·0		0·3	...	
			...		...		0·7		0·4			0·4	0·1			0·5		0·6	...	
			...		...			0·1*	0·2			1·0		0·0	0·3			0·5	...	
			...		...		0·1*		...			0·8	0·5			0·1		0·8	...	
			...		...		...		...			0·6	...		...			0·9	...	
			...		...		...		...			0·1	...		...			1·2	...	
			...		...		...		...		0·4		...		...			0·6	...	
			...		...		...		...		0·0		...		...			0·0	...	
			...		...		...		...		...		...		...			0·2	...	
			...		...		...		...		...		...		...		0·2		...	
Means			+0·4		−0·3		−0·1		+0·2		−0·4		−0·3		−0·2		−0·4		0·0	

Comparison between Carrington and Groombridge-Greenwich in N.P.D. for each 1° of N.P.D.

	0°.		1°.		2°.		3°.		4°.		5°.		6°.		7°.		8°.		9°.	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″
		0·3*	1·2*		0·7			0·1	0·9		1·2		0·5			0·3	1·7		1·4	
			0·1*		0·4*			0·4	0·8		1·8		1·3		1·7		0·8		0·4	
			0·2*		0·7		1·1		0·8*		0·5		0·4		1·7		1·6		0·5	
			0·9*		0·3*		0·7*		0·7*		1·8		1·5		2·3		1·6		1·2	
				0·3	...		1·1*		0·3		0·9		1·1		1·0		0·4		0·9	
			0·3*		...		1·4		1·2		0·6		1·4		1·0		1·1		0·9	
			...		...		1·2		1·9		1·0		1·3		1·6		1·5		1·4	
			...		...		0·2*		1·1		1·1		1·0			0·6	0·7		...	
			...		...		0·2		0·4		0·6		1·3		2·8		1·2		...	
			...		...		0·5*		1·2		1·3		1·2		1·2		2·6		...	
			...		...		0·4*		...		0·9		0·8		0·5		1·5		...	
			...		...		...		...		0·9		...		...		2·0		...	
			...		. .		...		...		1·0		...		...		1·5		...	
			...		...		...		...		1·5		...		...		1·7		...	
			...		...		...		...		0·3		...		...		2·0		...	
			...		...		...		...		...		...		...		1·4		...	
			...		...		...		...		...		...		...		0·4		...	
Means			+0·3		+0·5		+0·6		+0·9		+1·0		+1·1		+1·2		+1·4		+1·0	

Reference Numbers from Carrington's and Groombridge's Catalogues of the Comparison Stars for each 1° of N.P.D.

0°.		1°.		2°.		3°.		4°.		5°.		6°.		7°.		8°.		9°.	
Carr.	Groomb.	Carr.	Groomb.	Carr.	Groomb.	Carr.	Groomb.	Carr.	Groomb.	Carr.	Groomb.	Carr.	Groomb.	Carr.	Groomb.	Carr.	Groomb.	Carr.	Groomb.
1035*	1119	117*	144	140	175	145	195	52	67	451	595	1538	1633	593	774	76	100	346	506
		181*	235	956*	1141	236	339	131	177	1127	1359	2080	2063	1165	1391	1021	1255	429	580
		1834*	1884	1830	1871	491	642	575*	750	1516	1620	2105	2079	1222	1431	1045	1278	675	856
		1972*	2006	2316*	2283	842*	1004	770*	944	1746	1818	2222	2170	1807	1858	1301	1480	2348	2275
		2048	2065	...	...	1793*	1850	782	956	1790	1848	2261	2196	2360	2286	1381	1537	2350	2276
		3058*	3308	...	...	2122	2099	1205	1418	1818	1860	2404	2313	2550	2422	1558	1643	3140	3268
		3138	3402	...	[illegible]	2258	2210	2001	2007	1836	1879	2648	2476	3323	3597	1580	1662	3149	3276
						2755*	2628	3441	3820	1843	1889	2729	2548	3387	3707	1698	1778		
						2771	2667	3444	3824	1847	1892	2820	2708	3389	3709	1707	1782		
						3273*	3548	3693	4193	1882	1923	2822	2712	3502	3928	1774	1842		
						3621*	4101	...	...	1913	1937	3525	3970	3681	4174	1784	1843		
										1914	1940	...	...	...	...	1868	1909		
										2271	2213	...	...	...	...	1889	1927		
										3091	3212	...	...	...	...	1968	1977		
										3123	3260	...	...	...	...	2088	2071		
																3133	3261		
																3189	3370		

An asterisk (*) denotes that the star was one of Carrington's special polars.

The Total Solar Eclipse of 1908 *January* 3.
By A. M. W. Downing, D.Sc., F.R.S.

There are two Pacific islands favourably placed for the observation of this eclipse, viz. Hull Island, one of the Phœnix group, and Flint Island, one of the Line group. The astronomical details of the eclipse for these two islands are given below, the calculations having been made from the data of the *Nautical Almanac*. As the errors of the Moon's tabular places now amount to sensible, and apparently increasing, quantities, observers are warned that the calculated times of the various phases of the eclipse may differ considerably from the observed times, the calculated times being (with the present values of the errors) too late. In order to obviate, as much as possible, inconvenience arising from this cause, I have added in each case the intervals in time from the instant when the cusps subtend an angle of certain specified value at the Sun's centre to the commencement of totality.

The plans of the islands here reproduced are taken from the official charts published by the Hydrographic Office. The geographical details are abridged from the *Admiralty Sailing Directions, Pacific Islands*, vols. ii. and iii., 3rd ed., 1900.

The offices of Levers' Pacific Plantations Company, mentioned below, are situated at Port Sunlight, Cheshire. Intending observers of the eclipse should communicate with the Company at this address.

My thanks are due to Capt. A. M. Field, R.N., F.R.S., for his kindness in referring me to the available sources of information regarding these islands.

HULL ISLAND. Long. 172° 13′ W. Lat. 4° 30′ S.

Mean Solar Time.

	Greenwich. d h m s	Local. d h m s	Angle from North Point. °	Angle from Vertex. °
First Contact. ...	Jan. 3 7 18 33	Jan. 2 19 49 41	281	5
Total Eclipse ...	3 8 30 36	2 21 1 44	88	162
	3 8 33 27	2 21 4 35	294	8
Last Contact ...	3 9 58 12	2 22 29 20	100	155

Duration of totality, 2m. 51s.

Sun's altitude at totality, 43°.

Angle of Cusps. °	Time before Commencement of Totality. s
90	34
60	13
45	7
30	3
15	$\frac{3}{4}$

FLINT ISLAND. Long. 151° 48′ W. Lat. 11° 26′ S.

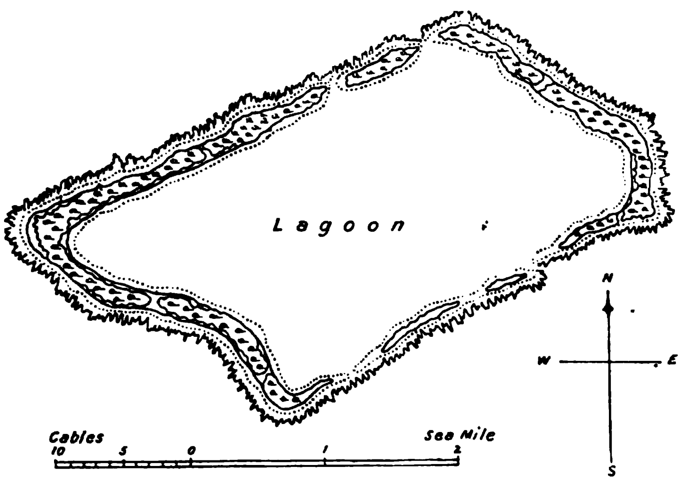
Mean Solar Time.

	Greenwich. d h m s	Local. d h m s	Angle from North Point. °	Angle from Vertex. °
First Contact. ...	Jan. 3 7 52 51	Jan. 2 21 45 39	278	355
Total Eclipse ...	3 9 22 44	2 23 15 32	107	153
	3 9 26 44	2 23 19 32	262	308
Last Contact. ...	3 11 2 59	3 0 55 47	90	42

Duration of totality, 4m. 0s.

Sun's altitude at totality, 74°.

Angle of Cusps. °	Time before Commencement of Totality. s
90	47
60	18
45	10
30	4
15	1



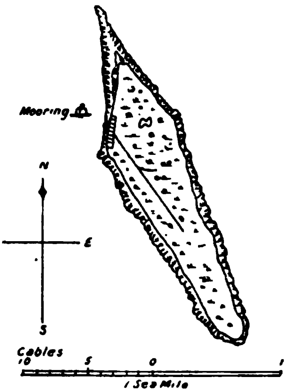
Hull Island.

HULL ISLAND (British) was discovered and so named by Wilkes in 1840. It has a lagoon and a little fresh water, and cocoanut trees on it, about 50 feet high. A coral reef fringes the island, and landing is difficult except by entering the lagoon by means of the boat passages on the north-west side. There is no anchorage.

In 1899 there were no inhabitants on the island.

It is now leased to Levers' Pacific Plantations Company.

The winds are almost constantly from the eastward, but squalls, accompanied by light rain, occur in the neighbourhood all the year round. The wind is variable from January to May, during which period bad weather is most common.



Flint Island.

FLINT ISLAND (British), discovered in 1801, is 13 feet high, covered with brushwood and trees, and is visible from the masthead from a distance of 16 miles. It is about $2\frac{1}{2}$ miles long N.N.W. and S.S.E., half a mile wide, and is fringed by a steep coral reef which dries at low water, and extends seaward generally about half a cable, but off the northern end of the island it extends seaward $4\frac{1}{2}$ cables, and off the southern end E.S.E. $2\frac{1}{2}$ cables. In the interior are two small lagoons of brackish water.

In 1880 October the island was uninhabited, and the buoys formerly in use were gone.

It is now leased to Levers' Pacific Plantations Company.

There is little or no rise and fall of tide at Flint Island.

The landing is very bad even for surf-boats, but it is said to export nearly 200 tons of copra annually.

Preliminary Account of Flash Spectra taken 1905 *August* 30. By S. A. Mitchell, Ph.D.

Upon the invitation of Admiral Chester, Superintendent of the U.S. Naval Observatory, the writer became a member of the United States expedition to observe the total eclipse of the Sun. The party crossed the Atlantic in the three men-of-war, U.S.S. "Minneapolis," U.S.S. "Cæsar," and U.S.S. "Dixie."

Observations were made at three stations, one in Africa, near the central line at Guelma, the other two in Spain, of which one was an edge station at Puerto Coeli, and the second near the centre of the Moon's shadow path at Daroca. All three stations were fortunate in having perfect weather conditions.

At Daroca were located Professor Eichelberger and Mr. Yowell, of the Naval Observatory; Professor Bigelow, of the U.S. Weather Bureau; Mr. Hoxton, of the Johns Hopkins University; and the writer. The programme of work included :—

A. Meteorological Observations, Professor Bigelow.

B. Photographs of Corona with 40-ft. horizontal camera, Mr. Hoxton.

C. Photographs of Corona with

(*a*) 104 in. } Mr. Yowell.
(*b*) 36 in. (5 in. aperture) }

D. Spectroscopic work, Dr. Mitchell.

Five spectrographs were employed, three being grating instruments, the other two alike having a dispersion of one weak prism.

The results of the photographs are as follows :—

1. *Parabolic Grating.*—This spectrograph was used without a slit, and consisted of a Rowland grating—ruled, however, on a parabolic surface instead of on the usual concave—and a photographic plate. It was placed horizontally, and a light was fed to it by a transit of *Venus* cœlostat, which, however, did not work with the highest degree of precision. The grating was four inches in diameter, with 14,438 lines to an inch and a focal length of five feet. The exposures were made by Ensign A. G. Howe, U.S.N., of the "Minneapolis." The spectrum was exceedingly bright in the first order on one side, and definition was splendid. The flash extends from D_3 at the end of the long wave-lengths to λ 3300 in the ultra-violet.

The dispersion is practically the same as the three prism spectrographs of the Lick and Yerkes Observatories, so that the distance from D_3 to H is almost exactly seven inches, the total length of the photographed spectrum being 9·5 inches. The lines of the flash have not been counted, but they are probably more than 1500 in number. As the definition is excellent throughout and the spectrum is "normal" it is probable that wave-lengths will be determined with a high degree of accuracy.

The spectrum taken near mid-totality shows some interesting coronal rings. The ring in the green due to "coronium" is very plain, and besides there are two rings in the extreme ultra violet which are just as prominent on the photograph as the green ring. As the photographic action of the plate used is about as intense in the green as in the ultra-violet (λ 3400), where the sensitiveness falls off very quickly, it would seem that the corona is very rich in ultra-violet rays. The following lines are seen in the corona at wave-lengths which are approximately λλ 3381, 3388,

3455, 3643, 3984, 4228, 4565, 4618, and the "coronium" line at λ 5303.

2. *Flat grating*, with 15,000 lines per inch and a ruled surface of $3\frac{1}{2} \times 6$ inches. This was used with a Clark 5-inch visual lens of 6 feet focus, and was employed without a slit. The instrument placed horizontally in connection with a Gaertner cœlostat was used on the eclipse day by Dr. Mitchell, assisted by two sailors of the U.S.S. "Minneapolis." On the photograph the distance from D_3 to H is eight inches. In the flash spectrum lines can be seen beyond the D lines toward the red almost to C. This is the end of the spectrum most desired with this instrument, and the focus is excellent from F to the extreme of the red. The green "coronium" ring also appears on the plates taken near mid-totality.

3. *Short focus concave grating* with a ruled surface of 4×6 inches, with 3610 lines per inch, and a radius of curvature of 64 inches (focus 32 inches). On account of its small dispersion, the spectra were excessively bright, and it was intended to record the changes in the bright lines just before and just after totality by photographing the second and third orders of spectra on the same plate, and making a number of exposures in quick succession at second and third contacts, the times of exposures being recorded on the chronograph. This instrument was in charge of Ensign F. McCommon, U.S.N. However, as totality began about ten seconds before calculated time, the exposures at second contact which were to run on both sides of the "flash" were all inside totality. In addition, the chronograph pen failed to write, and, as no one was watching it, this was unnoticed till totality was over.

4. *Two prismatic spectrographs* of the same dispersion were used in an attempt to find the intensity of the corona in different parts of the spectrum. This was to be done by photographing on the same plate, above and below the corona, comparison spectra of the Sun taken under ordinary conditions and with different exposures. Photometric measures could then have been made.

The Smithsonian Institution bolometric determinations give the energy of the Sun in different parts of the spectrum. If these eclipse photographs had been successful the energy of the corona at different regions would have become known. The instruments were used with slits, and each consisted of one prism with the necessary collimator and objective. No photometric measures were possible, for the reason that the coronal spectra were very faint, caused no doubt by the plate being slightly fogged from the diffused light in taking the comparison spectra.

Columbia University, New York City:
1906 February 13.

Note on Mr. Reynolds's Dark-slides. By A. E. Conrady.

At the suggestion of Professor Turner I have collected all available information concerning the above in the hope that it may prove useful in future.

It appears that these slides were made from a log of Spanish mahogany originally cut into boards fifteen years ago, the wood having been kept by the makers of these slides for the last nine years, and used in the making of a large number of slides, none of which have ever shown any sign of fogging plates excepting those taken to Egypt by Mr. Reynolds.

When the slides were returned to the makers, plates were inserted, and the slides kept in a dark-room for about a week, when on development the plates were found decidedly fogged, excepting where a strip of tinfoil had been interposed between the wood and the film. It is thus evident that the slides were then capable of fogging plates even at a comparatively low temperature, and the experiment further showed that, whatever the emanation or radiation might be, it was incapable of acting through tinfoil. Unfortunately it was found quite impossible permanently to fasten tinfoil inside the shutters, but it was found that a heavy coating of the usual optical black, that is to say, essentially a mixture of shellac and lamp-black, also stopped the action entirely, and this was the method by which the slides were put right.

It must still remain an open question what caused these particular slides to acquire the undesirable peculiarity; possibly exposure to the extreme heat and dryness of Central Egypt may have had something to do with it, as it is certainly a fact that out of the large number of dark-slides made from this particular log Mr. Reynolds's slides were the only ones to show this property.

It would indeed seem advisable, when slides are to be used in the taking of photographs which cannot be replaced afterwards, severely to test them before use under as nearly as possible the conditions which they will have to face in the actual work.

I may add that these particular slides were not newly made for the eclipse; on the contrary they were manufactured two and a half years before, and had been in stock ever since.

Note on certain Anomalies observed in Radial Velocity Curves. By Alex. W. Roberts, D.Sc.

Those whose researches lead them in one direction of an inquiry regarding the causes which underlie short-period variation must be impressed, as well as oppressed, with the great area of uncertainty which surrounds the whole subject.

At first sight we seem to know practically nothing of the immediate circumstances which produce variation of the definite type to which such stars as η *Aquilæ* and δ *Cephei* belong.

And yet the uncertainty is neither complete nor final. We are convinced, for example, that revolution and variation, or it may be rotation and variation, are connected together in some intimate relation, and that a solution of the problem of short-period variation will be obtained when we are able to declare what the nature and extent of this relation is.

Any investigation, therefore, that purposes dealing with the measures of radial velocity obtained by spectroscopic observation must have a direct bearing on the wider problem of stellar variation. By considering the orbital movement of any binary system that also exhibits light pulsations, we are approaching this problem from a less difficult and probably a more hopeful direction.

It is as a contribution to variable star astronomy, rather than to spectroscopic research, that I offer this note on certain anomalies observed to exist in the velocity curves of variable stars of the short-period type.

If two stars whose dimensions are relatively very small compared with the size of the orbit they move in are bright enough to be observed spectroscopically, then their radial velocity curve will be of a very simple type.

The curve will reveal the orbital movement of the stars and nothing more. There will be no anomalies to consider.

If, however, the size of the stars is distinctly comparable with the size of their orbit—that is, if the components are near enough to mutually distort each other—then the radial velocity curve is no longer that due to the revolution of two practically distant globular particles round each other, but is instead the velocity curve of two contiguous ellipsoidal masses of matter—a somewhat different condition of things. In this latter case the observed radial velocity curve will be a sinuous line on either side of a mean curve computed on the assumption that the component stars are two luminous points.

Another grave disturbing element is introduced when the contiguous stars move in an eccentric orbit. It is evident that with eccentric movement there will be a corresponding rhythmic flux of figure. As the stars approach each other they will become more elongated; as they recede they will naturally tend to a more spherical form. This alternate contraction and expansion of the major axis of figure and the synchronous expansion and contraction of the minor axis must produce a secondary variation in the mean radial velocity curve, a variation depending largely upon the contiguity of the component stars, and the eccentricity of the orbit they are moving in. This secondary variation will also be considerably modified by the inclination of the orbit, the position of the line of apsides, and the density of the circling stars.

As our knowledge regarding the laws which govern the actual alteration in figure of gaseous masses is so uncertain, and the relation in such systems of pressure to form so complicated, we may leave this physical cause of secondary radial velocity undealt with until we have considered those more geometrical conditions of position and figure which, theoretically at least, produce a departure from the mean velocity curve.

With one of these conditions, viz. the ellipsoidal form of the component stars, we have a more sure groundwork of fact to build upon, and I purpose considering in a very general manner

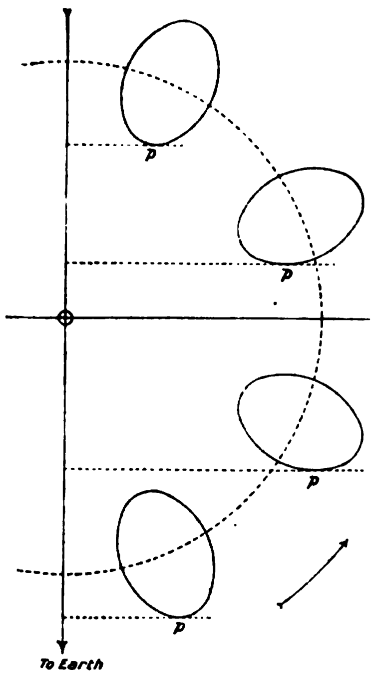


Fig. 1.

the character of the secondary sinuous curve produced by the revolution of such a body round the centre of gravity of its system.

It is evident that if the figure of a close binary star departs considerably from the spherical form, then the actual observed velocity curve will vary in a certain definite manner from the mean velocity curve. The reason for this is that the velocity recorded by the spectroscope is not that of a particle at the centre of the revolving star, but of an envelope of particles forming the outer shell of the prolate mass. If this shell be

spherical there will practically be no aberration in velocity; but if it be ellipsoidal, or apioidal, then there will be a departure from the mean velocity curve the extent of which will be measured by the prolateness of the star.

To give a less abstract character to this note let us consider fig. 1 to represent a bright star revolving round a centre, O, in the direction indicated by the arrow. Let there be three planes of reference at right angles to one another: the tangent plane perpendicular to the line of sight, the vertical plane in which the line of sight lies, the horizontal plane containing the line of nodes. The intersection of the second and third planes is the line of sight, and all pass through the point O.

Now if fig. 1 represents four positions of the bright component, then the radial velocity of a particle at the point p, where the tangent plane or a parallel plane touches the circumference of the star, will more correctly define the true velocity curve of the system (considering its figure to be constant) than any other point within or on the outer surface of the star.

It will be evident that the velocity of the centre of the star will not come within the area of actual observation; it has only a theoretical value and importance as furnishing the mean velocity curve on either side of which the apparent or true velocity curve varies. Since we do not see the centre we cannot regard the observed velocity curve as representing the velocity of this point. It represents the velocity of some other point or assemblage of points, and in my judgment it represents the velocity of p, the point where the tangent plane or a parallel plane touches the star.

Accepting this conclusion as a working hypothesis we may readily compute the amount of radial variation due simply to the prolateness of the component stars.

Let

θ = angular distance of bright star from line of sight at time T_1

$(\theta+\Delta\theta)$ = angular distance of bright star from line of sight at time T_2

ι = inclination of system

ϵ = prolateness of star

ac = semi-axis major of star

a_1 = projected semi-axis major of star on vertical plane at time T_1

a_2 = projected semi-axis major of star on vertical plane at time T_2

then

$$a_1 = ac\sqrt{1-\sin^2\theta\cos^2\iota\epsilon^2}$$

$$a_2 = ac\sqrt{1-\sin^2(\theta+\Delta\theta)\cos^2\iota\epsilon^2}$$

If now

$$T_2 - T_1 = \text{one second of time},$$

and thus

$$\Delta\theta = \text{angular velocity of bright star in one second of time},$$

then, neglecting higher powers of $\Delta\theta$ than the first, the correction to the mean velocity curve at any time T_1 becomes

$$\frac{ac}{2} \cdot \frac{\sin\Delta\theta \sin 2\theta \cos^2 \iota\epsilon^2}{\sqrt{1-\sin^2\theta\cos^2\iota\epsilon^2}}.$$

The ruling factor in this expression is $\sin 2\theta$. Its existence indicates that the secondary curve crosses the primary at four nodal points.

Its full period is therefore fulfilled in half that of the primary curve.

It may be pointed out that in the remarkable series of researches on the variable star *W Sagittarii* recently carried out by Professor R. H. Curtiss, of the Lick Observatory, the existence of a secondary velocity curve with a period equal to half that of the primary was clearly established.

But before this investigation of Professor Curtiss was undertaken Professor Campbell, in 1901, proved that a similar secondary velocity curve existed in the case of the variable star *ζ Geminorum* (*Astrophysical Journal*, vol. xiii. p. 90).

We give in fig. 2 a representation of the velocity curve of *ζ Geminorum* obtained by Professor Campbell. The evidence of a secondary curve supervening on the primary is indisputable; whether its period is completed in half that of the primary is not so clear.

Although the simple fact that the figure of the revolving components of *W Sagittarii* and *ζ Geminorum* departs considerably from the spherical form will not, and cannot, explain all the secondary velocity variation observed in these stars, the ever-changing figure of the stars must also be taken into consideration; still I am convinced that it will explain the greater part of the bi-period aberration.

I hope in a succeeding paper to enter into a numerical inquiry as regards the satisfactoriness or the reverse of the foregoing partial explanation of secondary radial velocity variation.

I offer it now with the hope that it may give a direction to the thoughts of those who, like the writer, are perplexed at the complete lack of common standing ground, other than a similarity of period, between orbital movement and light variation of certain short-period variables.

At the risk of appearing to wander incontinently away from the subject I have set before me, I might urge that greater confidence would be begotten in the comparison between the velocity

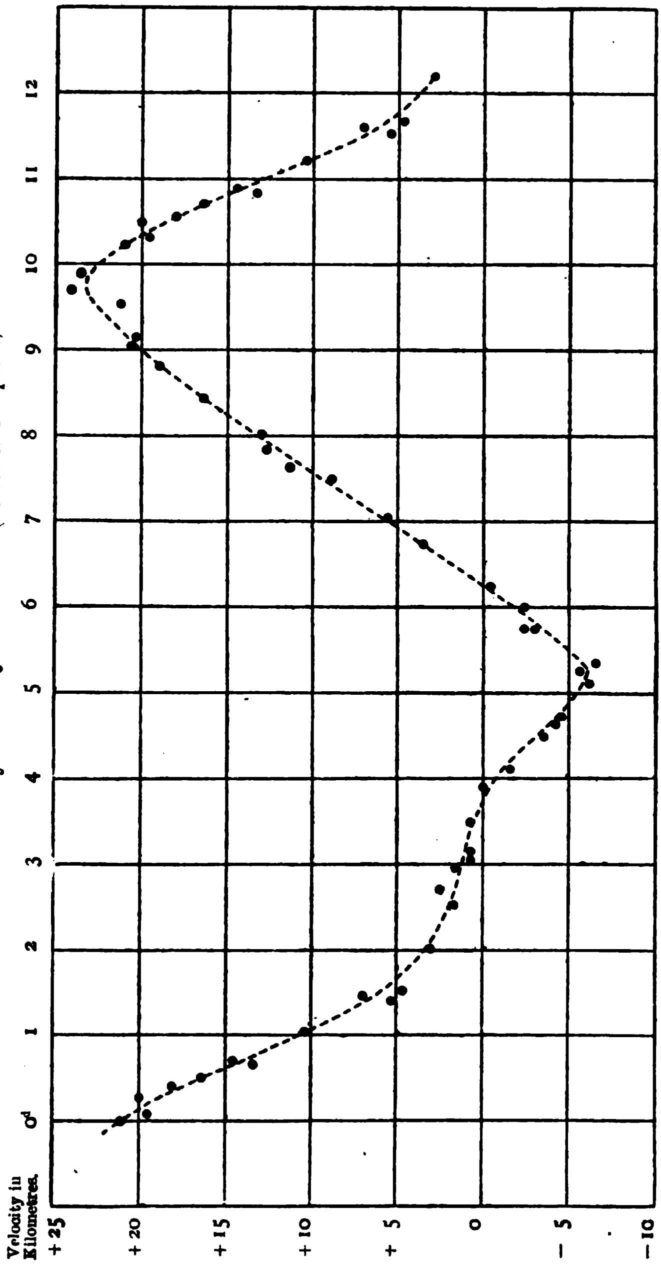


FIG. 2 Velocity Curve of ζ *Geminorum*. (Professor Campbell.)

curve and the light curve of any short-period variable if both curves were obtained synchronously.

To secure a certain velocity curve of a variable star and then, from its elements of variation, to bring up the light curve over possibly a lapse of years is exceedingly unsafe. Professor Curtiss's important correction in the case of *W Sagittarii* should stand as a warning against this mode of treating so important a problem.

What the writer would urge is that velocity observations and light observations should be made, *over the same period of time*, by reputed observers. One could then compare with confidence the two curves, and form a judgment of some weight on the comparison. There would be no necessity in such a case to consider the secular variation of period—always an uncertain factor.

In no way do I desire to detract from, or to throw discredit upon, the comparisons of the conditions of orbital movement and the circumstances of light fluctuations already established. My wish is to obtain as accurate and as absolute a comparison as care, experience, and skill can furnish.

Lovedale: 1906 *February.*

On the Variable Star (38'1905) *RX Andromedæ.*
By A. Stanley Williams.

$$\text{R.A.} = 0^{h}\ 56^{m}\ 26^{s}, \text{ Decl.} = +40^{\circ}\ 31'{\cdot}6 \ (1855)$$
$$\text{,,} \quad = 0\ 58\ 55 \quad \text{,,} \quad = +40\ 46{\cdot}2 \ (1900)$$

The few observations of this star obtained here during the latter portion of 1904 and the early part of 1905 seemed to show that it was a variable of the ordinary, regular, short-period (or δ *Cephei*) type, though with an unusually sharply accentuated maximum and a period as long as 45 days. The photographic observations published in the *Astronomische Nachrichten*, No. 4005, indicated, however, the existence of irregularities. Between 1905 July 30 and the end of that year additional observations were made on thirty-four nights,* and these show undoubtedly the presence of very remarkable irregularities. So that, having regard to the usually sharply defined maxima and to the long time during which the star generally remains faint, it would appear that the variable should henceforth be regarded as belonging to the type of *U Geminorum*. The observations upon which this conclusion has been founded are given here in full. It should be premised that these observations are of a more than

* Owing to the unfavourable weather there are many prolonged but unavoidable gaps in the series of observations.

usually satisfactory nature, so that I feel very positive as to the reality of the variations.

A diagram showing the positions of the variable and the comparison stars will be found in the *A.N.*, No. 4005. The following table gives the light-scale and rough magnitudes of the comparison stars used. These rough magnitudes are uncertain as regards their absolute values, but they will serve as a guide to the extent of the variations. They were obtained by assuming the star b to be 10·0 magnitude, and the value of a step to be 0·06 magnitude.

TABLE I.

Comparison Star.	Bright-ness	Assumed Mag.
b	36·4	10·00
c	21·7	10·88
d	20·7	10·94
e	15·0	11·28

Table II. contains the observations. These were all made with a $6\frac{1}{2}$-inch reflector, with a power of 73, except where otherwise mentioned. The state of the sky is indicated in the fourth column, where IV. implies extreme transparency. The interference from moonlight is also indicated in this column. The last column gives the brightness of the variable according to the light-scale of Table I.

TABLE II.

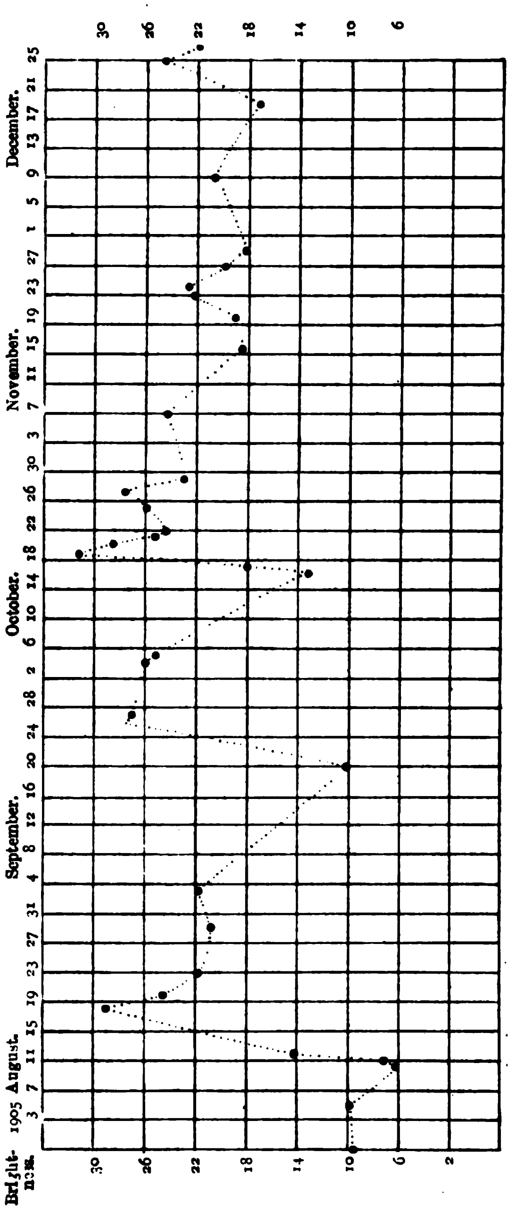
Date. 1905.	G.M.T. h m	Observations.	Sky.	Brightness.
July 30	12 33	c 12 v, d 10 v, e 7 v	IV.	9·5
Aug. 5	14 29	d 10 v, e 6 v	IV.	9·8
10	13 30	d 13 v, e 10 v	IV.	6·3
11	14 44	d 14 v, e 7 v	IV.	7·3
12	14 45	(v 7 d o e)	IV.	14·3
18	15 14	b 10 v 10 c, v 15 d	III. ☽ ☽	29·0
20	14 41	v 3 d, v 12 e, b 15 v 2 c	IV. ☽	24·4
23	14 30	c 2 v 5 d, v 10 e, b 20 v	III. ☽	21·7
29	13 12	d o v 6 e	II.	20·8
Sept. 3	11 10	c o v, v 1 d, v 7 e	III.	21·8
20	15 59	d 11 v, e 4 v	III. ☽ ☽	10·3
27	13 45	b 15 v 7 d, v 12 e, v 7 c	III.	26·8
Oct. 4	9 34	v 5 c, v 5 d, v 12 e, b 13 v	IV.	25·7
4	14 10	v 5 d, v 12 e	IV.	26·3
5	9 26	(c 4 v), b 14 v, v 4 d, v 12 e	IV. ☽	25·3
16	9 48	d 8 v, e 1 v	III. ☽ ☽ ☽	13·3

Date. 1905.	G.M.T. h m	Observations.	Sky.	Brightness.
Oct. 17	11 56	d 4 v 5 e	III. ☽ ☽	18·1
19	10 17	b 10 v 11 d, v 12 c, v 20 e	IV. ☽	31·6
20	10 20	b 15 v 7 c, v 8 d, v 18 e	II.	28·6
21	14 30	b 17 v 4 c, v 4 d, v 12 e	IV. ☽	25·2
22	8 32	b 18 v 2 c, v 4 d, v 12 e	IV.	24·5
25	11 10	b 15 v 7 d, v 15 e, v 7 c	III.	25·8
27	10 14	b 17 v 5 c, v 7 d, v 18 e	III.	27·7
29	10 37	b 18 v 2 c, v 1 d, v 9 e	IV.	23·0
Nov. 7	9 40	v 3 d, v 11 e, b 16 v 3 c	III. ☽ ☽ ☽	24·4
16	9 30	d 4 v 7 e, (d 11 e)	III. ☽ ☽	18·6
20	9 57	d 3 v 8 e	IV.	19·2
23	8 55	d o v 12 e, c o v. d 12 e	IV.	22·4
24	9 10	v 1 c, v o d, v 12 e	III.	22·8
27	7 15	d 2 v 7 e, c 1 v	IV.	19·8
29	7 25	d 4 v 10 e, c 4 v	IV.	18·4
Dec. 9	7 06	v o d	III. ☽ ☽ ☽	20·7
19	9 38	d 5 v 3 e	III.	17·1
25	10 16	b 12 v 4 d, v 3 c	II.	24·6
27	9 48	b 18 v, c 1 v o d, v 11 e	III.	21·9

Notes.—Aug. 12. Probably should be d 7 v o e and so treated; Aug. 29. Some thin cloud about; Sept. 20. Power 110; Oct. 5. c 4 v should probably be v 4 c; Oct. 16. Power 110, sky very bright; Nov. 16. "e very faint to-night?" * Dec. 9. Sky very bright.

The irregular nature of the variations will be seen clearly from the annexed diagram. From minimum brightness on August 11 the star rose rapidly to a sharply defined maximum three or four days later. It was again near minimum brightness on September 20, and a few days later it had risen to a maximum apparently not so sharply defined as the previous one. So far there is nothing very abnormal. But then, after declining to a minimum about October 16, the star rose very rapidly to a very sharply defined maximum on October 19, only about 23 days later than the preceding one. Subsequently to October 19, but subject to minor fluctuations, the star seems to have declined pretty steadily in brightness to December 19, shortly after which date another maximum occurred, probably about December 23. This long decline, during which the variable remained moderately bright, is itself remarkable, though, owing to gaps in the series of observations caused by bad weather, it is just possible that there may have been a maximum somewhere in the interval of 65 days. For the same reason, gaps caused by bad weather, there is an uncertainty of a day or two in the dates of

* The comparison star e may be slightly variable.



Light Curve of *RX Andromedæ* in the year 1905.

the observed maxima. These may, however, be put as under without likelihood of serious error.

Observed Maximum.		Interval. Days.
1905	Aug. 17	
	Sept. 26	40
	Oct. 19	23
	Dec. 23	65

Two maxima derived from my earlier observations are 1904 December 9 and 1905 January 24, the interval between the two being 46 days. These were both sharply accentuated maxima. The following time-intervals between successive maxima of *SS Cygni*, another variable of the same type, obtained by Dr. E. Hartwig in 1904,* will be interesting for comparison with the foregoing figures—namely, 58, 45, 34, 26, and 36 days. Hartwig further states that small brightenings (*Aufhellungen*) also occur when this star is faint, and that the minimum brightness differs at different epochs, all which might equally well be said to apply to *RX Andromedæ*. In fact, as regards the latter, it would seem that not only are the intervals between successive maxima highly irregular, but that also the star is fainter at some minima than it is at others, and that throughout the course of its changes it is subject to minor variations. And yet there are all through persistent suggestions of periodicity. It is worth noting that the successive minima were each brighter than the one preceding. Thus, August 12, brightness = 6·3; September 20 = 10·3; October 16 = 13·3; and December 19 = 17·1. Two distinct types of maximum were observed by Knott in the case of *U Geminorum*—one a sharply defined one, and the other flatter and more prolonged.† These apparently correspond to the "short" and "long" maxima of *SS Cygni*, as described by Messrs. J. A. Parkhurst and Z. Daniel.‡ The maxima of *RX Andromedæ* of 1905 August 17 and October 19, evidently belong to the former or "short" type, whilst in that of 1905 September 26 we may perhaps recognise the other or "long" type.

Hove: 1906 *February* 28.

* *V. J. S.* 39, Heft 4. p. 260.

† *Journal Liv. Ast. Soc.*, vol. iii. p. 119, and the accompanying diagrams.

‡ *Astrophysical Journal*, vol. xii. p. 267. See also *Popular Astronomy*, vol. vi. p. 159.

Observations of Comet c 1903 *from Photographs taken with the 30-inch Reflector of the Thompson Equatorial at the Royal Observatory, Greenwich.*

(*Communicated by the Astronomer Royal.*)

The following positions of Comet *c* 1903 were obtained from photographs taken with the 30-inch reflector. As a rule there were four images on each plate with exposures of two minutes during June, of one minute July 1 to 7, and of thirty seconds to the end. Four reference stars were taken in each case, situated as symmetrically as possible about the comet. The positions of these stars were derived from the catalogues of the Astronomischen Gesellschaft and from *Karlsruhe Observations*, 1885·0.

Date and G.M.T. 1903.	Apparent R.A.	Apparent Dec.	Log Δ.	Correction for Parallax. R.A.	Correction for Parallax. Dec.
d h m s	h m s	° ′ ″		s	″
June 24 13 16 40	21 49 11·35	− 5 27 58·9	9·8196	− ·33	+ 11·0
26 13 13 34	21 47 58·77	− 3 20 56·6	9·7811	− ·34	+ 11·8
27 12 59 1	21 46 39·41	− 2 10 7·5	9·7619	− ·38	+ 12·1
29 13 14 9	21 43 25·16	+ 0 33 21·4	9·7211	− ·35	+ 12·9
30 13 19 2	21 41 28·67	+ 2 6 26·5	9·6996	− ·34	+ 13·3
July 1 13 9 47	21 39 17·97	+ 3 47 31·9	9·6752	− ·37	+ 13·8
3 12 42 40	21 34 2·59	+ 7 40 10·3	9·6290	− ·46	+ 14·5
6 12 32 24	21 22 55·41	+ 15 11 45·0	9·5582	− ·50	+ 14·8
7 12 26 36	21 18 2·08	+ 18 15 13·8	9·5338	− ·53	+ 14·6
9 12 25 0	21 5 35·73	+ 25 22 45·1	9·5094	− ·50	+ 12·5
10 11 46 54	20 57 51·49	+ 29 21 3·4	9·4885	− ·68	+ 11·8
12 11 44 12	20 36 51·14	+ 38 28 23·0	9·4531	− ·66	+ 7·9
13 11 17 44	20 23 0·73	+ 43 19 4·2	9·4401	− ·79	+ 5·8
15 11 11 4	19 43 37·80	+ 53 17 30·2	9·4268	− ·61	− 0·5
20 11 58 38	16 11 14·71	+ 68 39 9·2	9·4718	+ 2·76	− 1·7
24 9 37 39	13 30 23·01	+ 64 39 6·7	9·5550	+ 2·13	+ 1·9
26 11 34 21	12 45 47·75	+ 60 48 31·3	9·5997	+ 1·82	+ 11·6
30 10 24 34	11 58 49·69	+ 54 12 16·4	9·6855	+ 1·26	+ 10·4
Aug. 1 9 35 39	11 44 26·04	+ 51 27 38·0	9·7254	+ 1·10	+ 9·0
4 9 3 14	11 28 4·58	+ 47 53 19·8	9·7810	+ 0·90	+ 8·3
5 9 19 58	11 23 28·60	+ 46 48 17·8	9·7981	+ ·83	+ 8·8
6 9 26 51	11 19 14·15	+ 45 46 48·3	9·8152	+ ·77	+ 9·0
7 9 12 54	11 15 19·08	+ 44 48 51·2	9·8313	+ ·74	+ 8·6
10 9 30 11	11 4 32·47	+ 42 4 32·1	9·8777	+ ·60	+ 8·8
13 8 45 25	10 54 54·26	+ 39 32 30·9	9·9200	+ ·54	+ 7·7
14 8 48 34	10 51 45·97	+ 38 41 45·1	9·9335	+ ·51	+ ·7

The value of log Δ, used in computing the correction for parallax, was taken from the ephemeris given in *Ast. Nach.* 3881 to July 7, and that in *Ast. Nach.* 3883 from July 9.

Further details of the observations will be given in the Greenwich volume.

1906 *March* 7.

Observations of Comet e 1904 *from Photographs taken with the 30-inch Reflector of the Thompson Equatorial at the Royal Observatory, Greenwich.*

(*Communicated by the Astronomer Royal.*)

The following positions of Comet *e* 1904 were obtained from photographs taken with the 30-inch reflector. On January 10, 19 and February 11 there was one exposure of twenty minutes on each plate. On January 25, 27 and February 2 there were two exposures of twenty minutes on each plate. Four reference stars were taken in each case situated as symmetrically as possible about the comet. The positions of these were derived from the catalogues of the Astronomischen Gesellschaft.

Date and G.M.T. 1905.	Apparent R.A.	Apparent Dec.	Log Δ.	Correction for Parallax. R.A.	Correction for Parallax. Dec.
d h m s	h m s	° ′ ″		s	″
Jan. 10 6 5 36	1 30 20·45	− 0 21 24·7	0·0837	−0·01	+5·70
10 6 43 50	1 30 23·00	− 0 20 6·8	0·0837	+0·04	+5·67
19 6 23 43	1 45 38·11	+ 6 39 5·2	0·1097	+0·04	+4·83
25 7 3 39	1 57 1·80	+11 6 17·1	0·1267	+0·10	+4·29
27 6 57 46	2 1 0·26	+12 31 48·8	0·0428	+0·12	+5·05
Feb. 2 6 32 52	2 13 32·02	+16 38 46·0	0·0603	+0·10	+4·41
11 7 8 2	2 34 10·72	+22 22 20·6	0·0878	+0·16	+3·70

The value of log Δ used on January 10 is taken from the ephemeris given in *Ast. Nach.* 3988, on January 19 and 25 from that in *Ast. Nach.* 3989, and on January 27 and February 2 and 11 from that in *Ast. Nach.* 3990–91.

Further details of the observations will be given in the Greenwich volume.

1906 *March* 7.

Observations of Occultations of Stars by the Moon made at the Royal Observatory, Greenwich, in the year 1905.

(*Communicated by the Astronomer Royal.*)

Day.	Phenomenon.	Telescope.	Power.	Moon's Limb.	Mean Solar Time of Observation. h m s	Observer.
1905. Jan. 10	Disapp. ϕ Aquarii	Thompson Equat. (Hodgson)	100	Dark	5 8 40·14	D. E.
10	,, ,,	Astrographic Equatorial	225	,,	5 8 40·32	W.
10	,, ,,	Sheepshanks Equatorial	100	,,	5 8 40·82	S. D.
10	Reapp. ,,	Thompson Equat. (Hodgson)	100	Bright	6 22 18·71	D. E.
17	Disapp. Bradley 686	Merz Refractor	250	Dark	9 39 27·11	C. D.
17 (*a*)	,, ,,	Astrographic Equatorial	225	,,	9 39 26·52	H. F.
17	,, ,,	Sheepshanks Equatorial	100	,,	9 39 26·73	S. D.
18 (*a*)	,, 130 Tauri	Astrographic Equatorial	225	,,	5 57 50·76	H.
18	,, ,,	Great Equatorial	670	,,	5 57 49·96	H. F.
18 (*b*) (*c*)	,, ,,	Sheepshanks Equatorial	100	,,	5 57 49·88	W.
18	,, ,,	Great Equatorial (Corbett)	120	,,	5 57 49·36	R. C.
18	,, ,,	Old Altazimuth	100	,,	5 57 (52·27)	S. D.
19	,, 26 Geminorum	Merz Refractor	250	,,	4 50 20·06	P. M.
19	,, ,,	Sheepshanks Equatorial	100	,,	4 50 20·84	J. S.
19	,, ,,	Astrographic Equatorial	225	,,	4 50 20·88	W. S.
19	,, ,,	Great Equatorial	670	,,	4 50 21·12	B. E.
Feb. 17	,, W. B (2) VIII. 211	Astrographic Equatorial	225	,,	6 36 19·63	W. S.
17	,, ,,	Sheepshanks Equatorial	100	,,	6 36 21·06	R. C.

Day.	Phenomenon.	Telescope.	Power.	Moon's Limb.	Mean Solar Time of Observation. h m s	Observer
1905. Mar. 12 (*a*)	Disapp. 48 Tauri	Astrographic Equatorial	225	Dark	7 53 36·73	H.
12	„ „	Sheepshanks Equatorial	100	„	7 53 36·80	H. F.
12	„ „	Old Altazimuth	100	„	7 53 (34·50)	J.
16 (*a*)	„ Piazzi VII. 261	Astrographic Equatorial	225	„	10 4 23·75	H.
16	„ „	Sheepshanks Equatorial	100	„	10 4 24·14	J.
19	„ 56 Leonis	Great Equatorial	670	„	11 2 9·30	D.
19	„ „	Great Equatorial (Corbett)	120	„	11 2 9·30	B. E.
Apr. 12	„ W. B. (2) VII. 685	Great Equatorial	670	„	6 38 13·72	W. B.
12	„ „	Sheepshanks Equatorial	100	„	6 38 13·71	W.
12	„ „	Merz Refractor	250	„	6 38 14·02	P. M.
12	„ „	Astrographic Equatorial	225	„	6 38 14·05	W. S.
12	„ „	Great Equatorial (Corbett)	120	„	6 38 13·72	V.
12	Reapp. „	Sheepshanks Equatorial	100	Bright	6 45 31·92	W.
12	Disapp. W. B. (2) VII. 761	„ „	100	Dark	7 35 34·59	V.
12	„ B. D. + 17°, 1612	„ „	100	„	7 42 49·21	V.
12	„ W. B. (2) VII. 782	Astrographic Equatorial	225	„	8 0 39·73	W. S.
12	„ „	Sheepshanks Equatorial	100	„	8 0 40·92	V.
12	„ W. B. (2) VII. 796	Astrographic Equatorial	225	„	8 5 57·86	W. S.
12	„ „	Sheepshanks Equatorial	100	„	8 5 58·37	V.
12	„ W. B. (2) VII. 793	Astrographic Equatorial	225	„	8 8 54·09	W. S.

Day.		Phenomenon.	Telescope.	Power.	Moon's Limb.	Mean Solar Time of Observation. h m s	Observer
1905. Apr. 12	Disapp.	W.B. (2) VII. 793	Sheepshanks Equatorial	100	Dark	8 8 53·98	V.
12	"	B. D. + 17°, 1619	Astrographic Equatorial	225	"	8 21 18·34	W. S.
12	"	B. D. + 17°, 1616	" "	225	"	8 23 6·05	W. S.
14	"	W. B. X. 431	" "	225	"	8 14 7·29	W. S.
14	"	Lalande 18635	" "	225	"	8 24 16·62	W. S.
15	"	44 Leonis	" "	225	"	8 2 43·54	H.
15	"	"	Great Equatorial	670	"	8 2 43·63	H. F.
15	"	"	Great Equatorial (Corbett)	120	"	8 2 43·83	Bies.
15	"	Piazzi X. 67	Astrographic Equatorial	225	"	8 13 56·88	H.
15 (*d*)	"	"	Great Equatorial	670	"	8 13 56·18	H. F.
15	"	Piazzi X. 67 (Comes)	Astrographic Equatorial	225	"	8 14 4·06	H.
15 (*b*)	"	"	Great Equatorial	670	"	8 13 59·66	H. F
15	Reapp.	44 Leonis	Astrographic Equatorial	225	Bright	9 13 58·66	H.
17 (*a*)	Disapp.	η Virginis	Sheepshanks Equatorial	100	Dark	8 17 11·64	H. F.
17	"	"	Astrographic Equatorial	225	"	8 17 12·35	W. S.
May 9	"	Lalande 14319	" "	225	"	9 7 3·91	W. S.
10	"	W. B. (2) VIII. 230	Sheepshanks Equatorial	100	"	9 31 44·91	H. F.
10	"	"	Astrographic Equatorial	225	"	9 31 45·06	W. S.

Day.	Phenomenon.	Telescope.	Power.	Moon's Limb.	Mean Solar Time of Observation. h m s	Observer.
1905 May 10	Disapp. W. B. (2) VIII. 260	Astrographic Equatorial	225	Dark	10 2 31·91	W. S.
15 (*d*)	,, 38 Virginis	,, ,,	225	,,	8 29 19·82	H.
15	,, ,,	Sheepshanks Equatorial	100	,,	8 29 19·95	J. S.
15 (*a*)	Reapp. ,,	Astrographic Equatorial	225	Bright	8 47 31·72	H.
15 (*a*)	Disapp. *k* Virginis	,, ,,	225	Dark	11 29 9·36	H.
15	,, ,,	Sheepshanks Equatorial	100	,,	11 29 9·46	J. S.
Sept. 19	Reapp. θ^1 Tauri	,, ,,	100	,,	16 36 10·82	J.
19	,, W. B. (2) IV. 450	,, ,,	100	,,	16 53 43·95	J.
Oct. 4	Disapp. B. F. 2471	Astrographic Equatorial	225	,,	6 36 26·26	W. S.
4	,, ,,	Sheepshanks Equatorial	100	,,	6 36 26·70	S. D.
Nov. 3	,, Piazzi XX. 250	Astrographic Equatorial	225	,,	5 51 27·08	W. S.
3	,, O. A. (S) 20742	,, ,,	225	,,	6 7 52·38	W. S.
3	,, B. D. – 17°, 6081	,, ,,	225	,,	9 10 9·33	W. S.
6 (*b*)	,, W. B. XXIII. 29	,, ,,	225	,,	5 39 35·82	W. S.
7	,, 27 Piscium	,, ,,	225	,,	7 29 49·28	H.
7	,, ,,	Great Equatorial	670	,,	7 29 49·02	H. F.
7	,, ,,	Great Equatorial (Corbett)	120	,,	7 29 49·22	J. S.
7 (*a*)	Reapp. ,,	Astrographic Equatorial	225	Bright	8 41 41·58	H.

Day.	Phenomenon.	Telescope.	Power.	Moon's Limb.	Mean Solar Time of Observation. h m s	Observer.
1905. Nov. 7 (*b*)	Disapp. 29 Piscium	Astrographic Equatorial	225	Dark	10 25 59·75	H.
7	" "	Sheepshanks Equatorial	100	"	10 25 59·92	J. S.
7 (*a*)	Reapp. "	Astrographic Equatorial	225	Bright	10 50 39·39	H.
Dec. 9 (*c*)	Disapp. *f* Tauri	" "	225	Dark	4 48 41·42	J. S.
9	" W. B. III. 569	" "	225	"	10 13 6·58	W. S.

Notes.

(*a*) Instantaneous. (*b*) Observation doubtful. (*c*) Very faint, foggy. (*d*) Not quite instantaneous.

The apertures of the telescopes used are as follows :—

	inches.		inches.
Great Equatorial	28	Great Equatorial (Corbett Telescope)	$6\frac{1}{2}$
Merz Refractor	$12\frac{3}{4}$	Thompson Equatorial (Hodgson Telescope) ...	6
Astrographic Equatorial (Guiding Telescope) ...	10	Old Altazimuth	4
Sheepshanks Equatorial	$6\frac{3}{4}$		

The initials D., H., C. D., D. E., W. B., H. F., W., J. S., P. M., W. S., R. C., S. D., V., B. E., J., Bies., are those of Mr. Dyson, Mr. Hollis, Mr. Davidson, Mr. Edney, Mr. Bowyer, Mr. Furner, Mr. Witchell, Mr. Storey, Mr. Melotte, Mr. Stevens, Mr. Cullen, Mr. Daniels, Mr. Vagg, Mr. B. Evans, Mr. James, and Mons. Biesbroeck respectively.

Royal Observatory, Greenwich :
1906 *March* 8.

Proposed Plan of the Basic Work of the Perth Observatory.
By W. E. Cooke, M.A.

When we have to design a programme of future work we ought to report our intentions to our "scientific world" and invite criticism. More especially is this the case with a new observatory, and I feel that I owe it to astronomers all over the world to state just what work I definitely propose that the Perth Observatory shall undertake and to invite the fullest criticism.

The Perth Observatory, it must be remembered, is at present only an infant, astronomically speaking. Its environment is not even yet free from disturbing elements, and it has already had several severe attacks, one of which nearly proved fatal. In this latter case its life was probably saved by the kindly intervention of the Royal Society. It will easily be understood therefore, that, with the work of the International Photo-Durchmusterung on hand, my thoughts have hitherto been mainly concentrated upon the immediate present. I have recently, however, had a short breathing space, and think that hopes may not unreasonably be entertained that the necessity for the existence of the Observatory is now recognised by our leading politicians, and that the work will be allowed to proceed undisturbed. Taking, then, for granted that this is an institution whose activities will proceed for centuries, it seems advisable from the start to lay down a programme for a century's work rather than one from year to year. If the Astronomer Royal were asked just wherein the Greenwich observations were so specially valuable, he would doubtless reply that it was because a definite programme (viz. the observation of the positions of the Sun, Moon, planets, and fixed stars) was originally laid down, and has been continued ever since.

We are at present engaged upon the Zone 32°-40° of the International Photo-Durchmusterung, and in connection with that work it has been necessary to select a list of standard stars for observation with the transit-circle. I have endeavoured to find three suitable ones in each square degree; though, of course, this has not been possible in all cases. *This list I propose to observe perpetually*, so that not only will there soon be a catalogue of reference points in this portion of the sky available for immediate use, but, as time goes on, the positions will be determined with greater and greater accuracy, and eventually also the proper motions.

My desire is to work through this list once every ten years, making three determinations of position of each star in each decade. To do this by the ordinary methods of fundamental work would be difficult or impossible with only two computers, who are also the observers, and who have other duties in addition to perform; and it will be necessary to contrive short cuts both for the observing and computing.

1. Professor Auwers has published (in *Astronomische Nachrichten*, Nos. 3431–2 and 4019–20) a "Fundamental-Catalog für Zonen-Beobachtungen am Südhimmel," and the stars of this catalogue situated between 31° and 41° declination will form the basis of reduction both in R.A. and N.P.D.

2. A list of 406 stars, also between those limits, has been prepared to act as secondary standards. These have been selected so as to succeed one another at intervals of three or four minutes in R.A., and so that there shall be at least three in each degree in every two hours of R.A. They include all the fundamental stars.

3. This list, with the addition of a few stars for azimuth, is now being exclusively observed. Clock and instrumental corrections are obtained from the fundamental stars, of which at least six are included in each night's work, and all the positions are thus reduced to the basis of Auwers' "Fundamental-Catalog."

4. It is hoped that one year's observations will give ten determinations of most of these secondary standards.

5. Observations of the main catalogue (of about 10,000 stars) will then be continued, and the instrumental constants will be derived from the positions determined for the secondary standards, of which at least six will be included in each night's work.

6. In this portion of the work the following method is proposed. The ordinary reticule will be replaced by one the idea of which has been suggested by a description of Mr. Hink's plate micrometer. There will be ninety-six horizontal wires in groups of four covering a space of 2°, *i.e.* the lines will be separated by 1′ spaces, but each fifth minute will be missing. The micrometer screw will be cut to about one revolution per minute, so that it need never be moved more than one revolution to pick up a star image in any part of the field. The slipping eyepiece will have a scale for giving the approximate micrometer reading, so that errors of 5′, or multiples of 5′, cannot very well occur. The telescope will be clamped for each evening at some definite degree of declination, and all stars within one degree north or south of this will pass through the field, and can be bisected on one or other of the horizontal wires with only a small turn of the micrometer screw. By this means the necessity for reading the circle will be eliminated, and much time will be saved both in observing and computing. Moreover, one very serious source of error will be eliminated, and the results will probably be more accurate.

7. The R.A. will probably be taken for the present in the usual manner by transit across seven wires, as I cannot afford to purchase a clockwork impersonal micrometer. I have, however, designed one rather different from the usual pattern, which I am hoping to have constructed locally.

8. Owing to the method of observing, the computations will be considerably simplified. The most serious portion of the work is of course the reduction from apparent to mean position.

Several methods, mechanical and otherwise, have already been proposed, and at present honours are about equally divided between Turner's and the Cape tables. I hope soon, in a separate paper, to place before the Society a method differing entirely from either of these.

9. It is hoped that with the present limited staff the whole catalogue (three determinations of each star) may be worked through every ten years. Should this be practicable there will gradually be formed a list of reference points situated between 31° and 41° decl. sufficiently well distributed and sufficiently accurately determined for most purposes for which a catalogue will be required. Moreover, by constantly observing the same stars year by year the observers will feel that not a single particle of their work is being wasted, and that their results, instead of becoming out of date and lost on library shelves, will become increasingly valuable decade after decade.

10. Observations of the zones 31°–34°, 39°–40° have been already made upon older-established principles, using *Nautical Almanac* clock-stars and nadir points; but these can probably be reduced to the new system. It may happen that an interruption to the whole scheme will shortly occur, as I have not yet been able to start measuring the plates for the Astrographic Durchmusterung. The whole of the catalogue plates will shortly be completed, and I may have to suspend all night-work in order to get them measured. An interruption of a few years, however, will make little difference to such a scheme as I have proposed.

The Observatory, Perth, Western Australia:
1905 *November* 11.

Errata in Annual Report.

Vol. lxvi. p. 176, line 9 from bottom, *for* transit of *Mercury* *read* transit of *Venus*.

Page 217, line 21 from bottom, *for* Oello *read* Ocllo.
" 217, " 17 from bottom, *for* Genna *read* Genua.
" 254, diagram of *Polaris*, *for* 1898 August *read* 1899 August.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXVI. APRIL 11, 1906. No. 6

W. H. MAW, Esq., PRESIDENT, in the Chair.

Rev. Walter Briscombe, Hillam Royd, Abbey Park Road, Grimsby;

Arthur Stanley Eddington, B.Sc., B.A., Royal Observatory, Greenwich; and

Dr. Edalji Manekji Modi, F.C.S., &c., Sleater Road, Bombay,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

John de Fenton, Ph.B., Secretary, Seymour Avenue, Parktown, Johannesburg, South Africa (proposed by R. T. A. Innes);

John Grigg, The Observatory, Thames, New Zealand (proposed by W. Steadman Aldis); and

Robert Leetham Jones, M.A., Barrister-at-law, 3 King's Bench Walk, Temple, E.C. (proposed by Fredk. W. Crowe).

Professor Julius Franz, Observatory, Breslau, Germany, was proposed by the Council as an Associate of the Society.

Ninety-four presents were announced as having been received since the last meeting, including, amongst others :—

G. W. Hill, collected mathematical works, vol. ii., presented by the author; Lowell Observatory Annals, vol. iii., presented by Professor Lowell; Telegraphic determinations of longitude,

1888–1902, made under the direction of Sir W. H. M. Christie; and eighteen charts of the Astrographic Chart of the Heavens, presented by the Royal Observatory, Greenwich; two lantern slides of spectroheliographs of the Sun taken at Kodaikánal Observatory, presented by the Director; six large transparencies from photographs of the Milky Way taken by Professor E. E. Barnard at Mount Wilson, California, presented by the Yerkes Observatory.

A Tentative Explanation of the Apparent Secular Acceleration of the Earth's Orbital Motion. By P. H. Cowell.

I have recently shown that, in order to satisfy the ancient eclipses of the Sun and Moon, it is necessary to assume that the mean longitude of the Moon contains a term $+11'' T^2$, and that the mean longitude of the Sun contains a term $+4'' T^2$.

These two arbitrary assumptions satisfied six solar eclipses. It was inconceivable that this could be a mere coincidence. Moreover, in the lunar eclipses of the Almagest, if we try to satisfy the records by assuming unknown secular accelerations for both Sun and Moon, we are led to precisely the same conclusions. I have felt it impossible to doubt that the records are trustworthy, and that no tables of the Sun and Moon will be completely satisfactory that fail to agree with those records.

There is still, however, some latitude of interpretation left. The eclipses determine at certain times the relative positions of the Sun, Moon, and node of the Moon's orbit. Two relations in fact exist between the four quantities, the position of the Sun, the position of the Moon, the position of the node, and the time.

The history of the subject is briefly as follows:

Halley discovered the secular acceleration of the Moon, Laplace showed that the changes produced by the planets in the eccentricity of the Earth's orbits would produce effects of the kind noted by Halley, Adams first correctly calculated the secular acceleration of the Moon's mean motion, and Professor Brown has given (*Monthly Notices*, lvii. p. 348) the following numerical values of the secular accelerations per century (measured from a fixed or uniformly moving departure point):

For the mean motion	$+5''.91$
For the node	$+6.56$

From the ancient eclipses I obtained as observed values of the secular terms:

For the distance from the Sun to the Moon ...	$+7''$
For the distance from the node to the Sun ...	-2.4

The excess of the observed over the theoretical secular accelerations is therefore :

From the Sun to the Moon	$+1''$
From the node to the Sun	$+4$
From the node to the Moon	$+5$

The mean motions of the Sun and Moon can only be obtained from observation, whereas the mean motion of the node can be obtained from theory; as the theoretical motion of the node agrees with observation at the present time, it seems more reasonable to attribute the above excess of observed over theoretical secular accelerations to the Sun and Moon rather than to the node.

The observed excess to be explained is therefore :

For the Moon	$+5''$
For the Sun	$+4$

Since the time of Lagrange (who, by the way, refused to believe in the secular acceleration of the Moon as an observed fact until this idea had occurred to him) it has been considered permissible to assign any secular acceleration of the Moon to a lengthening of the day. If the day increases in length by one part in a million, the mean motion of the Moon would appear to increase by one part in a million ; so also would the Sun's mean motion ; but the numerical increase would only be one thirteenth part as large as for the Moon.

Mr. Eddington reminded me that Sir George Darwin has pointed out that the principle of conservation of angular momentum implies that, if the Earth is losing its axial rotation, the Moon's orbit must be at the same time expanding, and its angular motion diminishing.

Let N, n denote the angular velocities of the Earth's rotation and of the Moon's revolution, and let δN, δn denote the variations of these quantities in a century; then the apparent secular acceleration of the Moon is

$$\tfrac{1}{2}\left(-\frac{\delta N}{N}+\frac{\delta n}{n}\right) \text{ times its mean motion}$$

and the apparent secular acceleration of the Sun is

$$\tfrac{1}{2}\left(-\frac{\delta N}{N}\right) \text{ times its mean motion}$$

where the factor $\frac{1}{2}$ is introduced, because secular accelerations are defined as the coefficients of T^2 in the corresponding quantity, instead of $\frac{1}{2}T^2$.

δN, δn are both negative quantities, and it is easily shown that $\frac{\delta n}{n}$ is a very large fraction of $\frac{\delta N}{N}$, and hence that the ratio of the Moon's secular acceleration to its mean motion is a small fraction of the corresponding ratio for the Sun if tidal friction be the cause.

This is precisely the inference from ancient eclipses:

For the Sun the observed ratio is

$$4'' \text{ to } 100 \text{ revolutions, or } 3 : 10^8$$

For the Moon (excess over the Laplace effect)

$$5'' \text{ to } 1336 \text{ revolutions, or } 3 : 10^9$$

To fit in with these numbers it is necessary to show that

$$\frac{\delta n}{n} = \frac{9}{10}\frac{\delta N}{N}$$

so that

$$-\frac{\delta N}{N} + \frac{\delta n}{n} \text{ may be one tenth of } -\frac{\delta N}{N}$$

Let I be the amount of inertia of the Earth, m, a, e the mass, mean distance, and eccentricity of the Moon; then the moment of angular momentum is

$$I \,.\, N + mna^2(1-e^2)^{\frac{1}{2}}$$

The principle of the conservation of angular momentum will only give one relation between δN, δn and δe; but this relation is sufficient to show that $\frac{\delta n}{n}$ must be a large fraction of $\frac{\delta N}{N}$, though not necessarily nine tenths.

Differentiating and neglecting the effect of solar tides,

$$I\delta N + mna^2(1-e^2)^{\frac{1}{2}}\left[-\tfrac{1}{3}\frac{\delta n}{n} - \frac{e\delta e}{(1-e^2)}\right] = 0$$

or

$$-k\frac{\delta N}{N} + \tfrac{4}{3}\frac{\delta n}{n} + 4\frac{e\delta e}{1-e^2} = 0$$

where k is approximately unity, if we assume that the Earth's moment of inertia may be calculated as if it were homogeneous.

In this equation put $k = 1$, $\delta e = 0$

then $$\frac{\delta n}{n} = \tfrac{3}{4}\frac{\delta N}{N}$$

which proves, at any rate, that $\frac{\delta n}{n}$ is a large fraction of $\frac{\delta N}{N}$. Also the ratio is increased if a positive value is assigned to δe.

In the same equation substitute the observed values

$$\frac{\delta N}{N} = -6 : 10^8 \qquad \frac{\delta N}{N} - \frac{\delta n}{n} = -6 : 10^9$$

(the factor 2 being introduced) then

$$\delta e = (\tfrac{6}{5} - k)\,\frac{2\cdot7}{10^7} = 0''\cdot01 \text{ per century if } k = 1$$

The supposition that the observed accelerations follow from the theory does not therefore conflict with the observed eccentricity.

On the other hand the transits of *Mercury* exhibit some slight evidence against this hypothesis, but perhaps not sufficiently important to destroy it.

Two conclusions follow from this paper:

I. It is absolutely wrong to assign an arbitrary secular acceleration to the Moon and none to the Sun, and to justify this course by the supposed action of the tides. This has been the practice of the *Nautical Almanac* since 1883.

II. On the hypothesis contained in this paper the rate at which the day is increasing is six parts in 10^8 or $0^s\cdot005$ per century. This is about ten times as large as previous estimates.

Observations of the Magnitudes and Position of Nova Geminorum

By E. E. Barnard.

This star was discovered by Professor H. H. Turner on a photograph taken at Oxford on 1903 March 16.

My work on the Nova has consisted of comparisons of its light with that of certain stars and measurements of its position relative to small stars near it. I have also watched the star for any change of focus due to the usual changes in the spectrum of a Nova. The star was at first of a strong red colour, but this soon faded out and left it colourless. At first there did not seem to be any difference in the focus from that of an ordinary star, but in the latter part of April there seemed to be some slight difference, the star perhaps coming to a focus slightly outside of that for an ordinary star (see *Ap. J.* xvii. 1903, p. 376). The notes show that on 1903 August 31 the Nova was whitish and hazy. On 1903 September 21 at $15^h\ 45^m$, with a magnifying power of 700 diameters, the Nova was decidedly out of focus when compared with the other stars. Careful measures

of the focus were made with reference to a 10th magnitude white star preceding.

Nova	... ...	2·54 inches	(5 obs.)
10^m star	... ...	2·25 „	(6 „)
Difference	...	0·29 inch	

The focus for the Nova was therefore 0·29 inch further from the object-glass than for a star. On 1905 November 25, by slipping the eyepiece back and forth, the focus for the Nova seemed to be quite outside of that for a star, but the seeing was too bad to make any measure of it. Speaking of the focus of the Nova, there was one thing about it that I have never seen in the case of any other star. In experimenting with the focus on 1903 March 30 I found that the star really had two distinct foci, both of which gave sharp definite images, one of about the 8½ magnitude, of a reddish-yellow colour at the ordinary focus for a star, the other of the 10th magnitude 0·39 inch further out from the object-glass and of a beautiful crimson colour and 0″·1 in diameter. This last image was really the best defined of the two. In the first case there was an inconspicuous crimson halo about the star, and in the second a pale greyish-blue halo 3″·8 in diameter. Either of these images would readily have been taken for the true image of the star. On April 6 this crimson image was still present though not so strong and definite. On April 27 it had entirely disappeared. The out-of-focus image of the Nova then resembled that of an ordinary star. On account of cloudy weather it had not been possible to tell just when this change took place. I understand that this crimson image was due to the strong Hα line in the spectrum of the star. When the other stars were examined outside and inside the focus no such peculiarity was seen.

Mr. Parkhurst had secured a photograph, 1903 February 21, with the 2-foot reflector of the region of the Nova. On this plate a faint star was shown close to the position afterwards occupied by the Nova; this small star, however, was near the edge of the plate where spherical aberration made it difficult to measure with accuracy. It was thought that this might be the Nova before it became bright. When the Nova had faded sufficiently, however, to permit one to see a faint object near it, I found on the morning of 1904 September 1 that the small star itself could be seen close preceding the Nova. Measures of the position of this star with respect to the Nova are given in the list of measures that follows.

A few of these measures were given in *Ap. J.* xvii. 1903, pp. 301, 302. In those measures, however, the magnitudes assigned the small stars were only rough, simply to aid in the identification of the stars. On two dates since then I have carefully estimated their magnitudes. This is rather important because these estimations are on the same scale that I have used throughout

in my measures of the small stars in the globular clusters. These estimations are given below :

Direct Estimates of the Magnitudes of Small Stars near Nova Geminorum.

	1903 Oct. 26. m	1904 Dec. 5. m	Mean. m		1903 Oct. 26. m	1904 Dec. 5. m	Mean. m
1	13·0	13·5	13·2	5	12·8	12·6	12·7
2	13·8	14·2	14·0	6	12·8	13·4	13·1
3	15·0	14·5	14·7	7	...	...	15·1
4	12·8	12·5	12·7				

The magnitudes of five of these stars have been determined photometrically by Mr. Parkhurst. They are :

	m		m
1	13·29	6	13·11
3	14·84	7	15·27
5	13·00		

In *Ap. J.* xvii. 1903, pp. 376, 377, I have given my determinations of the magnitudes of the Nova from 1903 March 27 to May 19. To make the present paper more complete I will give here these results, which depend on stars whose magnitudes were photometrically determined by Mr. Parkhurst. They are based on the Harvard system. The observations of May 23 and 27 were not printed in the *Ap. J.*

Observed Magnitudes of Nova Geminorum.

1903.	Central Standard Time. h m	Mags.	1903.	Central Standard Time. h m	Mags.
March 27	12 30	8·00	April 26	8 30	9·81
29	9 0	8·81	27	8 30	9·96
30	9 0	8·82	28	8 30	10·18
31	7 20	8·84	May 3	8 20	9·80
April 3	8 0	8·96	6	8 10	9·80
4	7 40	9·04	7	9 10	9·87
6	9 0	9·15	8	8 30	9·77
7	10 20	9·22	10	8 10	9·77
9	8 0	9·12	18	8 30	10·02
16	7 40	9·12	19	8 30	10·07
17	9 0	9·20	23	8 30	10·05
22	7 50	9·20	27	8 50	10·05
24	8 15	9·92			

At the observation of March 27 the star was very low and the estimated magnitude is unreliable. A direct estimate made it 8·2 magnitude. It was estimated to be 0·2 magnitude less than B.D. + 29°, 1342.

Magnitudes of the Nova when Faint.

	h m	m			h m	m
1903. Aug. 31	16 25	12 ±	Rough estimate	1904. Oct. 17	14 0	13·7
Sept. 1	16 0	11 ±	Rough estimate	Nov. 12	13 40	13·8
Oct. 13	14 30	12·3		21	17 40	14·4
26	14 30	12·3		26	11 40	14·5
27	14 0	12·3		Dec. 5	10 45	14·3
Dec. 14	11 10	12·3				
29	15 30	12·3		1905. Oct. 31	17 0	14·5
1904. April 19	9 50	12·2		Nov. 25	15 40	14·9
May 2	7 55	12·1		Dec. 23	14 30	14·8
3	7 50	12·1		30	13 10	14·4
Oct. 1	14 45	13·6		1906. Feb. 27	11 30	14·8

These determinations depend upon the magnitudes of the stars given in the measures.

The Nova is now but little brighter than the small star close preceding it (the one thought to be the Nova on the photograph of 1903 February 21). With bad seeing the light of the two stars mixes, and this makes any comparison of the light of the Nova somewhat uncertain. The last observation seemed to be a good one.

The measures of the position of the Nova do not seem to show any certain motion in that object. Nor does there seem to be any indication of a parallax.

Nova Geminorum.

Nova and 1.

		°	″	
1903 Mar. 30		104·82	32·21	
Apr. 4		105·22	32·52	
6		105·03	32·28	
7		104·97	32·38	
28		104·71	32·66	
Aug. 31		104·25	32·10	
Sept. 21		104·49	32·52	
28		104·35	32·36	
1904 Oct. 1		104·43	32·27	
17		104·38	31·98	
Nov. 12		104·94	32·08	
	Mean	104·60	32·30	
1905 Nov. 25		104·40	32·04	
Dec. 23		104·98	31·44	Very difficult.
26		103·86	32·22	
30		105·10	31·89	
	Mean	104·59	31·90	

There seems to be a decrease of distance between Nova and star 1. This change is not certain, and further measures will be made to settle the question of motion. If the motion is in the Nova it ought to tell in the distances of stars 7 and 8 also, and in the position angles of the other stars.

Nova and 4.

1903 Mar. 30		196°·15	84″·93	
Apr. 4		196·30	85·15	
6		196·29	84·99	
Aug. 31		196·03	85·07	
Sept. 21		196·14	84·99	
28		196·23	84·96	
1904 Oct. 1		196·14	...	Clouds.
17		196·29	85·06	
Nov. 12		196·52	85·07	
Dec. 5		196·27	84·96	
	Mean	196·23	85·02	
1905 Nov. 25		196°·61	85″·06	
Dec. 23		196·87	84·79	
26		196·24	84·93	
	Mean	196·57	84·93	

Nova and 2.

1903 Mar. 30		169°·20	45″·66	
Apr. 6		168·78	45·61	
27		168·83	46·31	Uncertain.
Sept. 21		168·72	45·73	
28		168·77	45·54	
1904 Oct. 1		169·52	45·24	
17		169·43	45·54	
Dec. 5		169·34	45·80	
	Mean	169·07	45·68	
1905 Nov. 25		169°·36	45″·63	
Dec. 23		169·69	45·25	
26		169·08	45·70	
	Mean	169·38	45·53	

Nova and 6.

1903 Mar. 30		16°·98	102″·81	
Apr. 4		17·45	103·00	
6		17·05	102·86	
7		17·31	102·78	
Sept. 21		16·89	103·13	
28		16·81	102·94	
Oct. 13		17·09	102·93	
1904 Oct. 17		17·22	102·76	
	Mean	17·10	102·90	

Nova and 5.

1903 Mar. 30		313°·86	99″·87	
Apr. 4		313·90	99·94	
6		313·87	99·86	
Sept. 28		313·78	100·11	
Oct. 13		313·80	99·87	
19		313·94	100·03	
26		313·72	99·98	
1904 Oct. 17		313·65	99·78	
Nov. 12		313·51	100·05	
Dec. 5		313·63	100·05	
	Mean	313·77	99·95	

Nova and 3.

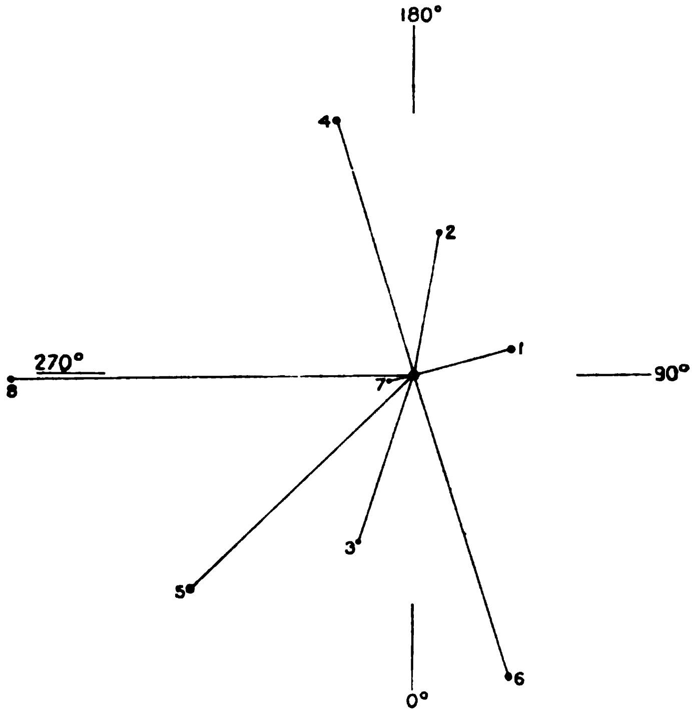
1903 Mar. 30		341°·61	55″·69	
Apr. 27		341·45	...	Too difficult for distance.
Oct. 26		341·45	55·64	
	Mean	341·50	55·66	

Nova and 7.

1903 Aug. 31		284°·35	7″·83	
Sept. 28		281·61	8·03	
Oct. 26		283·09	7·94	
27		283·77	7·60	
	Mean	283·20	7·85	

Nova and 8 ($14^{m} \pm$).

1903 Oct. 26		$270^{\circ}90$	$131''76$
27		270·83	131·27
Nov. 16		270·98	131·23
	Mean	270·90	131·42



The accompanying chart of these stars will make their identification easy, even if the Nova should entirely disappear.

High-level Chromospheric Lines and their Behaviour in Sun-spot Spectra. By A. Fowler.

About a year ago I communicated to the Society an account of some spectroscopic observations of the great sun-spot of 1905 February, and of the prominences observed when the spot was on the Sun's limb.* An attempt was then made to distinguish

* *Monthly Notices*, vol. lxv. p. 513.

between high-level and low-level lines in the spectrum of the disturbed chromosphere, and it was pointed out that the high-level lines were not among those intensified in the spot, while the lines common to spots and prominences were chiefly those of iron, chromium, and calcium which appear as strong Fraunhofer lines. Since then I have made numerous observations which furnish additional data for such a comparison; and although the records are not yet so complete as might be desired, the following notes may serve a useful purpose by drawing the attention of observers to some points requiring further investigation, while spots and metallic prominences are still relatively numerous. The Evershed two-prism solar spectroscope has been employed throughout, chiefly in conjunction with the 6-inch refractor at the Royal College of Science, South Kensington, but during 1905 August, in conjunction with a 4½-inch refractor at Castellon, Spain.

Continued attention has been given to the distinction between high- and low-level lines for the reason that Professor Young has not always made this distinction in his well-known list of chromospheric lines, and sufficiently good eclipse photographs of the less refrangible parts of the spectrum are not yet available. When observing the spectrum of a metallic prominence with a tangential slit, the high-level lines are recognised as such by their relatively great length, while the low-level lines are usually very short. In each case the lines are of various intensities, and some of the long lines are faint as compared with the brighter of the short ones. The longest lines of all are, of course, those of hydrogen and helium, but the term "high-level" may be conveniently understood to include all lines which show any considerable extension.

The lines observed on different occasions during the last two years have always been the same, so far as it was possible to determine their positions, and their relative intensities have been nearly constant; those at 5169·2, 5018·6, and 4924·1, however, have shown a certain amount of variation when compared respectively with b_1 and the helium lines 5015·7 and 4922·1.

All the long lines which have yet been noted, but not all the short ones, occur in Young's list, though not many of them are designated as high-level lines. The short lines, so far as they have been identified with terrestrial spectra, correspond with arc lines which are not enhanced on passing to the spark. The long lines, excluding the exceptionally long ones of hydrogen and helium, may be considered as of two varieties: one including the D lines of sodium and the *b* lines of magnesium, which are strong lines both in arc and spark; the other consisting of enhanced lines so far as their origin can at present be traced. Most of these enhanced-line identifications are due to Sir Norman Lockyer,* but my own investigations indicate that at least four

* *Phil. Trans.* vol. cxcvii. A, p. 151.

additional lines are to be assigned to iron, one to titanium, and one to chromium. Full details as to all the lines recorded are reserved until more observations have been secured, but the wave-lengths and intensities of the high-level lines, excluding those of hydrogen, helium, sodium, magnesium, and barium, are given in a table which follows.

The phenomena observed in these disturbances of the chromosphere seem to indicate, as suggested in my former paper and in accordance with the views of Sir Norman Lockyer, that the chromospheric "layers" are elevated without any great disturbance in their order. On this point Lockyer writes: * "If the Sun is quiet, or if we observe any particular part of it at any time at which it is not agitated, the layers visible at that time, few in number, are usually concentric, but the moment there is any agitation in the subjacent photosphere the lower layer shoots up into the next layer above it; the next shoots up into the one next above that; and so on; . . . from the very lowest layer to the upper hydrogen one the layers are made to obey this same impulse, and bulge up like so many domes on that part of the Sun which is being violently agitated."

The long lines, whatever their brightness, are more frequently observed than the shorter ones, because it takes a less violent disturbance to bring them into view. The shorter lines, notwithstanding their great brightness in some cases, are only seen on the comparatively rare occasions when the disturbance is sufficiently great to elevate the low-lying flash stratum to such a height that it can be differentiated from the photospheric spectrum. This, at all events, seems to provide a simple explanation of the appearances observed.

It thus appears probable that the metallic prominences yield occasional opportunities of observing the flash spectrum in addition to those furnished by eclipses, and since high dispersion may be employed the positions of the various lines may be determined with the accuracy essential for proper comparison with spot spectra and for purposes of identification.

The additional observations which have been made confirm generally my previous statement as to the relative behaviour of high-level and low-level lines in the spectra of spots, and Mr. W. M. Mitchell, of Princeton, states that his observations are in complete agreement upon this point.† Mitchell further observed that some of the high-level lines, so far from being intensified in the spots, are thinned or obliterated. My own observations have confirmed those of Mitchell in this respect and indicate additional examples of the same behaviour. Some of these, and others which I have confirmed by visual observations, are also indicated by the recent photographic records of Hale and Adams.‡

* *Chemistry of the Sun*, p. 169.
† *Astrophys. Journ.* vol. xxii. July 1905, p. 40.
‡ *Ibid.* vol. xxiii. January 1906, p. 11.

The extent of this thinning or obliteration of lines is possibly somewhat variable from spot to spot, but the varying amount of scattered light, depending on the state of the sky, makes it difficult to ensure certainty on this point. In an observation of the large spot in the south preceding quadrant on 1906 March 27, however, the thinning of the lines appeared to be unusually distinct, and on one or two occasions the line 5169·2 has been seen clearly bright over the umbra. Some of these lines are components of close doubles in the solar spectrum, and the thinning or obliteration then reveals itself as a notch on one side of the compound line where it is crossed by the spot. The iron line 5169·22 with its companion 5169·07 due to iron is one of the best examples; my attention was first drawn to it by Mitchell's paper, and I have since recognised other similar cases.

Particulars as to the approximate intensities of thirty high-level chromospheric lines and of their behaviour in spots are given in the following table. The wave-lengths and solar intensities are from Rowland's tables, and the enhanced-line identifications are Lockyer's, except for those marked F, which result from my own experiments. The prefix "p," as employed by Lockyer, is an abbreviation for "proto," and indicates that the line is relatively enchanced in passing from the arc to the spark spectrum. Under the heading "Spots" the numbers are intensities on the solar scale, except those of Mitchell, which are relative numbers such that -5 indicates complete obliteration. The general behaviour of the lines tabulated suggests that those which are still unidentified will be found to correspond with enhanced lines.

Wave-length.	Origin.	Intensity and Character in Chromos. (F)	Intensity in Sun. (R)	Spots. — (F)	Spots. Hale and Adams.	Spots. Mitchell.	Remarks.
4924·11	*p* Fe	25 *l*	5	Reduced to 3	Out of range	...	...
5018·63	*p* Fe	25 *l*	4	Much reduced	...	5	(1)
5154·24	*p* Ti	15 *l*	2	Reduced to 1	...	...	...
5169·22	*p* Fe	40 *l*	4	Nearly obliterated	·07 } weak on ·22 } red edge	-4	(2)
5186·07	*p* Ti_r	10 *l–s*	2	Reduced to 1	...	-3	...
5188·86	*p* Ti	15 *l–s*	2	Reduced	·86 } hazy towards ·02 } violet	2	(3)
5197·74	*p* Fe_r	25 *l*	2	Reduced to 0	Reduced to (0–1)	...	...
5226·71	*p* Ti	20 *l–s*	2	Reduced to 1	...	Obliterated once	...
5234·79	*p* Fe_r	25 *l*	2	Reduced to 0	Reduced to 1	-3	...
5237·49	*p* Cr_r	10 *l*	1	„ „	Reduced to (0–1)	-3	...
5264·98	...	15 *l*	0	Obliterated	Reduced to 00	...	...

Wave-length.	Origin.	Intensity and Character in Chromos. (F)	Intensity in Sun. (R)	Spots. — (F)	Spots. Hale and Adams.	Spots. Mitchell.	Remarks.
5276·17	*p* Fe	35 *l*	3	Not clearly affected	...	Generally not affected	(4)
5284·28	...	25 *l*	1	Nearly obliterated	...	...	(5)
5316·79	*p* Fe	45 *l*	4	Much reduced	...	...	(6)
5325·74	...	15 *l*	2	Reduced to 0	...	...	(7)
5336·97	*p* Ti	15 *l–s*	4	Reduced to 2	...	...	(8)
5363·06	*p* Fe_r	30 *l*	3	Much reduced	...	...	(9)
5381·22	*p* Ti	10 *l*	2	Reduced to (0–1)	...	...	(10)
5425·46	...	30 *l*	1	Nearly obliterated	Reduced to (0–1)	−4	...
5527·03	*p* Sc	20 *l*	3	Reduced to 2	...	...	(11)
5535·06	?*p* Fe_r	35 *l*	2	Reduced to 1	Reduced to 1	...	...
5991·60	...	15 *l*	2	Nearly obliterated	Out of range	...	...
6238·60	...	15 *l*	2	" "	" "	−4	...
6247·77	...	20 *l*	2	" "	" "	−4	...
6347·31	...	25 *l*	2	Obliterated	" "	−4	...
6369·68	...	10 *l*	0	...	" "	...	(12)
6371·57	...	15 *l*	1	Nearly obliterated	" "	...	(13)
6432·89	...	25 *l*	1	" "	" "	−4	(14)
6456·60	*p* Fe_r	20 *l*	3	Obliterated	" "	−4	...
6516·31	...	30 *l*	2	...	" "	...	(15)

Remarks.

1. A close double in Sun, Ni 5018·46 (1) and *p* Fe 5018·63 (4). The line is distinctly notched on red side.

2. A close double in Sun, Fe 5169·07 (3) and *p* Fe 5169·22 (4). Notched on red side, as first described by Mitchell.

3. A close double in Sun, *p* Ti 5188·86 (2) and Ca 5189·02 (3). Notch on violet side observed with difficulty, probably on account of widening of Ca line.

4. A very close double in Sun, *p* Fe 5276·17 (3) and Cr (?) 5276·24 (2). The widening of the chromium line possibly obscures the reduction of the *p* Fe line.

5. Rowland gives origin as Ti, but the line does not appear in Hasselberg's table. It may be an enhanced line, but the dispersion of my photographs does not clearly separate it from adjacent lines.

6. This is "1474 K." The reduced intensity is clearly seen in the reproduced photograph given by Hale and Adams. Young has also noted that the line is "distinctly weakened and sometimes reversed." There are closely adjacent lines at 5316·91 (0) and 5316·96 (2).

7. Young gives the wave-length of the chromospheric line as 5325·4. The reduced intensity of the dark line is seen in Hale and Adams' photograph.

8. The line is distinctly weakened in Hale and Adams' photograph.

9. A close double in Sun, Fe 5362·94 (1) and *p* Fe 5363·06 (3). The line is notched on the red side in spots.

10. Rowland attributes solar line to Fe.

11. Lockyer attributes this line to *p* Sc in *Roy. Soc. Proc.* vol. lxix. p. 359.

12. Rowland attributes solar line to iron. In my instrument it is too feeble in the Sun to determine whether it is reduced in spots or not, but it is certainly not intensified.

13. Rowland attributes solar line to iron.

14. Rowland gives Fe? for this line.

15. This line is difficult in my instrument on account of adjacent line at 6516·8; it is certainly not intensified in spots, and I believe that it is much reduced in intensity.

The general result of the comparison is to show that a Fraunhofer line agreeing in position with a high-level chromospheric line, if it be of "proto-metallic" origin, is especially liable to be thinned or obliterated in the spectra of spots. In many cases there is a sufficient agreement among the different authorities as to their behaviour in spots, while for others further independent confirmation is desirable. As indicated in the remarks, however, some of the reduced lines which are noted only in my own observations are confirmed by the photograph of Hale and Adams, though they are not shown in the tables of these observers. Many of my observations have also been confirmed by my assistant, Mr. Shaw.

By way of explanation it might be supposed that the vapours producing the enhanced lines in the chromosphere and the corresponding lines in the Fraunhofer spectrum are chiefly restricted to the higher levels, and that their thinning or obliteration in spot spectra is due to the actual withdrawal of the more elevated vapours from the region directly over a spot. On the other hand, the occasional brightening of some of the lines suggests that the chromosphere retains its continuity over the spots, and is sometimes of more than ordinary brightness. It is possible, therefore, that the reduced intensity is to be accounted for by the umbra not providing a sufficiently luminous background to strongly exhibit the absorption of the high-level vapours, while the lines themselves are rarely of sufficient intensity to appear bright.

Observations are somewhat conflicting as to the continuity or otherwise of the chromosphere over spots. Young writes:* "Respighi asserts (and the most careful observations we have been able to make confirm his statement) that, as a general rule, the chromosphere is considerably depressed immediately over a spot. Secchi, however, denies this." Further investigation of this matter is greatly to be desired.

It should be remarked in conclusion that there are many lines which are weakened in spots besides those to which reference has been made, but neither enhanced lines nor high-level chromospheric lines corresponding with them have yet been recorded. Many of these are probably lines of the "widened and weakened" type described by Mitchell, which, with moderate dispersion, are not clearly distinguishable from thinned or obliterated lines.

* *The Sun*, 1901 ed., p. 216.

The most definite conclusion indicated by the observations is that enhanced lines of iron, chromium, and titanium appear as high-level lines in the chromosphere, and that the corresponding Fraunhofer lines are generally enfeebled in the spectra of sun-spots.

[NOTE, April 28.—In *Bulletin* No. IV. of the Kodaikánal Observatory, received since the above paper was read, Mr. Michie Smith records two observations of the obliteration of 6247·77, one of 6347·31, and one of a line at 6084·32. It is interesting to note that the latter is described by Young as a faint high-level chromospheric line, though it is not yet included in my list.]

The Partial Eclipse of the Sun 1906 *February* 22, *observed at Adelaide.* By Sir Charles Todd, K.C.M.G., F.R.S.

(*Extract from a letter to A. M. W. Downing.*)

We observed the eclipse as follows :—

	h m s	
First contact	5 58 58	Considered good.
Last contact	6 58 42	Not good, Sun too low and limb very badly defined.

Adelaide standard times ($9^h\ 30^m$ East) of February 23.

Observatory, Adelaide:
1906 *February* 26.

On the Part played by Contrast in the Appearance of the Dusky Areas of Mars. By E. M. Antoniadi.

In his valuable "Observations of *Mars*, 1903" (*Monthly Notices*, vol. lxv. No. 8, June 1905, p. 840), Major P. B. Molesworth, R.E., has written that if my theory of contrast be "pressed to extremes it becomes a most dangerous argument. If we carry it to its logical conclusion we shall have a *Mars* deprived of all 'nuances' of light and shade, both light and dark markings being broad masses of uniform tone unrelieved by any half-tones or delicate shading."

Now in reply to this it is perhaps unnecessary to remark that any physical hypothesis is destined to account for some definite phenomena, and no others. The utility of pressing a theory to extremes is therefore questionable to my mind. At the same time Major Molesworth's "logical conclusion" from

the contrast hypothesis, that it would give absolute uniformity to the dusky areas of *Mars*, is gratuitous, and, moreover, in direct antagonism to facts, since contrast, as shown by observation and experiment, tends to intensify the edges of *all* duskinesses, and this quite independently of their albedo.

Major Molesworth has obviously misunderstood the expression "rough evenness of tint"* which I have applied to some dusky areas of the planet. The word "evenness" was used only in opposition to the unevenness resulting from Signor Schiaparelli's sea-girding "canals," which I have attributed to contrast.† That I never meant for a second that the grey markings of *Mars* were even in tint is evident (*a*) from the above expression, "rough" evenness implying, of course, a somewhat checkered structure of the shadings; (*b*) from the statement made in the very paper in which my contrast theory was framed in 1903, and running thus: "That the intensity of the grey spots is far from being uniform no one will deny";‡ and (*c*) from my numerous published maps of *Mars* from 1892 to 1903, and particularly the small chart accompanying the 1903 considerations on contrast, in which the intensity of the shadings is shown to vary most unmistakably, and by delicate gradations, from the faintest half-tones to the darkest areas.§ Such converging evidence goes far to establish beyond doubt the uselessness of the attempt to invalidate the contrast hypothesis by straining it to conclusions of a baseless and inaccurate character.

But Major Molesworth raises a far more interesting question when doubting that the intervention of contrast and of fatigue of the eye can be nugatory to eye training during the successive apparitions of *Mars*.‖ Examples, however, tending to prove the reverse are numerous. In 1890, for instance, Signor Schiaparelli's persistent efforts had reached, after several weeks of real eye-training, what looks like the culminating point in the visibility of delicate objective detail when Sinus Sabæus appeared with a wavy, irregular outline and a fairly uniform intensity (fig. 1). But what, may we ask, was the result of further observation? The disappearance of detail, the brightening of the inner part of the Strait, and the intensification in two very dark perfectly straight lines of the N. and S. borders (fig. 2).

Inasmuch as Major Molesworth considers that eye-training goes on steadily improving during a given apparition, he must logically admit the rude form of 1890 June 20 as giving a

* *English Mechanic*, 1903, No. 2016. † *Knowledge*, 1903, pp. 247, 248.
‡ *Ibid.* p. 248. § *Ibid.* p. 249.

‖ Here Major Molesworth asks if contrast is applicable to the duplicity of *Jupiter's* belts. These I consider objectively double in the immense majority of cases. There can be no comparison between the solid globe of *Mars* and gaseous *Jupiter*, whose rotation period varies with latitude. On *Saturn* contrast gives rise to the "square shoulder" appearance and to Dr. Terby's white spot on the rings.

truer view of Sinus Sabæus than that of May 16, the atmospheric definition being excellent in both cases and the probability of objective change on such a vast scale being out of question. But the evidently artificial character of such an assumption is avoided by the theory of contrast; considering fig. 1 to represent the best view of Sinus Sabæus, and the irregularly indented outline to look like the natural edge either of a vegetation tract

Fig. 1.
May 16.

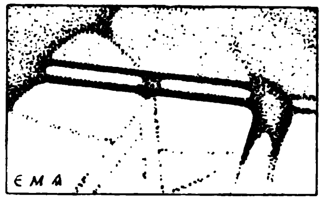


Fig. 2.
June 20.

Appearances presented by Sinus Sabæus in 1890 according to Signor Schiaparelli.

or of water, or a combination of both, fig. 2 corresponds to the vagaries of an exhausted retina, since, according to contrast, fig. 1 will appear like fig. 2 after a very prolonged fixity of gaze.* I have, however, an open mind; and the day when Major Molesworth will have succeeded in demonstrating that the amelioration of telescopic seeing by eye-training involves the positive *loss* of planetary detail he will have established his contention on a strong basis.

Observations of Comet a 1904, from Photographs taken with the 30-inch Reflector of the Thompson Equatorial and the 13-inch Astrographic Refractor at the Royal Observatory, Greenwich.

(*Communicated by the Astronomer Royal.*)

The following positions of Comet *a* 1904 were obtained from photographs taken with the 30-inch reflector, except that on 1904 April 17, which was taken with the 13-inch astrographic refractor. From two to four exposures were made on each plate, the duration being 3^m in 1904 April and May, 2^m in June, afterwards increasing to 7^m in October. The last photograph, on 1905 May 8, has two exposures of 20^m each.

* I attribute to a fatigue of the retina the disappearance of the faint half-tones of the N. hemisphere of *Mars* from the charts of Signor Schiaparelli and Mr. Lowell. The tired eye sees better the outlines than the central regions of faint duskinesses.

The plates were measured in the astrographic micrometer. Four reference stars were taken in each case, situated as symmetrically as possible about the comet. The positions were derived from the Catalogues of the Astronomische Gesellschaft.

Date.	G.M.T.	Apparent R.A.	Apparent Dec.	Log Δ.	Corr. for Parallax. R.A.	Corr. for Parallax. Dec.
1904.	h m s	h m s	° ′ ″		s	″
Apr. 17	11 21 31	16 56 20·23	44 44 31·9	0·3490	−·20	+1·2
18	11 19 59	16 53 34·02	44 22 5·6	0·3490	−·20	+1·2
19	10 24 14	16 50 48·65	45 57 48·9	0·3490	−·22	+1·5
20	9 25 34	16 47 58·55	46 32 55·8	0·3490	−·24	+1·9
20	10 37 52	16 47 49·39	46 34 45·8	0·3490	−·21	+1·3
21	10 30 41	16 44 46·95	47 10 38·6	0·3490	−·22	+1·3
25	9 52 42	16 31 42·01	49 27 17·9	0·3502	−·23	+1·2
25	10 26 28	16 31 36·97	49 28 5·2	0·3502	−·21	+1·0
26	10 40 1	16 28 3·31	50 0 56·2	0·3510	−·20	+0·8
26	11 15 56	16 27 57·82	50 1 44·0	0·3510	−·17	+0·6
27	9 34 44	16 24 35·68	50 31 9·9	0·3518	−·24	+1·2
27	9 46 59	16 24 33·81	50 31 26·2	0·3518	−·23	+1·1
May 2	9 46 8	16 5 6·89	52 56 22·0	0·3556	−·22	+0·7
2	10 3 52	16 5 3·85	52 56 41·8	0·3556	−·21	+ ·6
3	10 50 9	16 0 47·21	53 23 33·1	0·3570	−·16	+ ·2
4	9 34 15	15 56 47·45	53 47 10·3	0·3585	−·22	+ ·6
5	10 23 15	15 52 21·25	54 11 52·5	0·3599	−·17	+ ·2
7	11 17 8	15 43 24·72	54 57 2·9	0·3628	−·10	− ·1
9	11 8 50	15 34 26·11	55 36 41·0	0·3658	−·09	− ·2
11	9 25 11	15 25 35·56	56 10 37·2	0·3692	−·18	+ ·2
14	10 58 18	15 11 19·15	56 55 35·9	0·3752	−·05	− ·3
16	9 59 3	15 2 8·63	57 18 37·2	0·3791	−·10	− ·3
18	9 37 40	14 52 52·04	57 37 28·4	0·3842	−·11	− ·3
18	9 57 1	14 52 48·23	57 37 35·5	0·3842	−·09	− ·3
19	9 45 22	14 48 11·82	57 45 22·7	0·3865	−·09	− ·3
25	9 31 20	14 21 10·53	58 10 41·9	0·4008	−·05	− ·4
25	9 59 37	14 21 5·37	58 10 43·7	0·4008	−·01	− ·4
30	10 13 19	14 0 11·57	58 6 37·2	0·4125	+·05	− ·4
30	10 27 44	14 0 9·18	58 6 35·2	0·4125	+·07	− ·3
31	9 57 40	13 56 18·02	58 3 30·8	0·4151	+·04	− ·4
June 3	10 4 39	13 44 59·99	57 49 59·9	0·4230	+·07	− ·3
5	10 19 21	13 37 53·69	57 37 55·7	0·4284	+·10	− ·2
10	11 42 59	13 21 41·57	56 58 46·4	0·4417	+·20	+ ·4
16	10 29 21	13 5 38·76	56 0 52·7	0·4577	+·16	+ ·2
18	10 32 53	13 0 56·59	55 39 25·3	0·4630	+·17	+ ·3

Date.	G.M.T.	Apparent R.A.	Apparent Dec.	Log Δ.	Corr. for Parallax. R.A.	Corr. for Parallax. Dec.
1904.	h m s	h m s	° ′ ″		s	″
June 20	10 6 11	12 56 36·64	55 17 29·9	0·4683	+·16	+ ·3
20	10 17 24	12 56 35·60	55 17 24·7	0·4683	+·17	+ ·3
21	10 55 5	12 54 28·31	55 5 50·2	0·4709	+·19	+ ·6
21	11 9 21	12 54 27·00	55 5 43·4	0·4709	+·19	+ ·7
27	11 0 22	12 43 37·15	53 56 9·1	0·4862	+·19	+ ·8
28	10 30 41	12 42 4·62	53 44 36·4	0·4887	+·18	+ ·7
28	10 43 47	12 42 4·03	53 44 30·2	0·4887	+·18	+ ·8
29	10 28 16	12 40 34·60	53 32 48·3	0·4912	+·18	+ ·7
29	10 41 39	12 40 33·80	53 32 42·1	0·4912	+·18	+ ·8
July 1	10 28 2	12 37 44·72	53 9 10·1	0·4960	+·18	+ ·8
5	10 28 20	12 32 46·40	52 21 59·5	0·5055	+·18	+ ·9
6	10 14 45	12 31 40·66	52 10 23·6	0·5079	+·17	+ ·9
8	10 25 53	12 29 35·57	51 47 1·3	0·5125	+·18	+1·0
9	11 10 18	12 28 36·13	51 35 6·2	0·5147	+·18	+1·3
11	10 27 25	12 26 50·54	51 12 30·7	0·5192	+·17	+1·1
15	10 31 49	12 23 46·24	50 27 36·1	0·5279	+·17	+1·2
18	10 20 35	12 21 52·58	49 54 57·2	0·5341	+·17	+1·2
20	10 57 24	12 20 46·10	49 33 21·8	0·5380	+·16	+1·4
20	11 13 24	12 20 45·76	49 33 15·0	0·5380	+·16	+1·5
21	10 22 59	12 20 16·93	49 23 7·7	0·5399	+·16	+1·3
21	10 36 37	12 20 16·56	49 23 1·5	0·5399	+·16	+1·4
28	9 57 54	12 17 38·04	48 12 59·7	0·5530	+·15	+1·3
28	10 13 11	12 17 37·85	48 12 54·7	0·5530	+·15	+1·3
Aug. 2	9 55 2	12 16 30·33	47 26 21·9	0·5614	+·15	+1·4
4	10 22 49	12 16 12·37	47 8 23·2	0·5646	+·14	+1·6
6	10 0 51	12 15 59·67	46 51 13·9	0·5677	+·14	+1·5
8	9 55 32	12 15 51·69	46 34 29·4	0·5706	+·14	+1·5
12	9 50 57	12 15 48·20	46 2 35·3	0·5761	+·14	+1·5
17	9 45 53	12 16 3·06	45 25 44·1	0·5825	+·13	+1·6
17	10 4 15	12 16 3·16	45 25 37·6	0·5825	+·13	+1·7
18	10 39 1	12 16 8·84	45 18 29·9	0·5837	+·11	+1·8
24	9 33 51	12 16 57·29	44 39 53·1	0·5902	+·12	+1·6
24	9 42 42	12 16 57·43	44 39 51·5	0·5902	+·12	+1·7
26	9 36 35	12 17 19·10	44 28 2·1	0·5921	+·12	+1·7
29	9 0 48	12 17 55·21	44 11 25·5	0·5949	+·12	+1·6
Sept. 3	8 50 11	12 19 5·93	43 46 24·7	0·5988	+·12	+1·6
7	8 44 20	12 20 10·49	43 28 58·7	0·6015	+·12	+1·6
9	9 19 22	12 20 45·13	43 21 2·6	0·6027	+·11	+1·8
17	8 40 32	12 23 13·97	42 55 56·0	0·6064	+·11	+1·7

Date.	G.M.T.	Apparent R.A.	Apparent Dec.	Log Δ.	Corr. for Parallax. R.A.	Corr. for Parallax. Dec.
1904	h m s	h m s	° ′ ″		s	″
Sept. 19	7 45 44	12 23 52·66	42 51 14·2	0·6071	+·12	+1·5
20	7 42 26	12 24 12·69	42 49 4·6	0·6074	+·12	+1·5
Oct. 3	7 13 55	12 28 39·55	42 35 54·8	0·6090	+·11	+1·6
12	7 3 2	12 31 42·34	42 43 45·6	0·6076	+·11	+1·7
1905. Jan. 17	12 25 0	11 39 30·61	60 33 58·1	0·5471	−·17	+·1
25	11 48 7	11 16 58·30	62 19 41·0	0·5489	−·16	·0
Feb. 2	11 33 34	10 50 35·30	63 39 12·9	0·5536	−·14	−·3
25	11 37 46	9 28 25·59	64 15 16·9	0·5816	+·03	−·5
Apr. 12	10 21 6	8 3 36·90	56 41 20·8	0·6720	+·12	+·2
May 8	10 16 29	7 57 26·30	52 11 12·0	0·7223	+·11	+·7

Further details of the observations will be given in the volume of "Greenwich Observations."

Royal Observatory, Greenwich:
1906 *April* 10.

Note on the Effects of Difference of Sea and Air Temperatures on Marine Refraction. By the Rev. William Hall, R.N.

(*Communicated by the Secretaries.*)

Observers who use the sea-horizon are often confronted with a displacement of the visible horizon, which, while not amounting to *mirage*, is nevertheless capable of disturbing their "sights." It would appear that very little exists upon which to base a theory of such abnormal refraction, since none of the recognised text-books of nautical astronomy refer to it. I submit a few suggestions.

My attention was first drawn to the subject in 1897, when, in observing equal altitudes of the Sun for rating chronometers at Ras-el-Tin, Alexandria, I found a remarkable discrepancy in results, and was led to connect it with a *mirage* which occurred intermittently during the day. On the next days I took temperatures of air and of the sandy soil and obtained a series of about seven days' observations—about four sets per day—and tried graphic methods of getting some connection between the true and apparent altitudes. It seemed that a formula of the shape

$$R = a + bT^2$$

was indicated, T being difference of temperatures of air and sand.

My results were retained with a view to further experiment,

but the question was not again attacked until 1899, when some observations were made in latitudes ranging between 65° N. and the Equator. Finally, in 1903, continuous observations in the Mediterranean were made during the summer; there were then sufficient data to warrant analysis.

I suggest now that the temperature difference causes an abnormal refraction of two terms

$$R = f(h) + \phi(T)$$

$f(h)$ depends on h, the height of observer's eye, and is constant for a given height of eye. $\phi(T)$ depends on T, the temperature difference, and on h.

I cannot trace any connection between apparent altitude and the correction, although *à priori* one would expect that $\phi(T)$ would involve also the altitude and would vanish at alt. = 90°. Here, however, I admit there are but few data for high altitudes.

The following formula is given as a subject for criticism in the hope that it may either be proved reasonably correct or else be corrected by other observers:—

$$R = \tfrac{1}{20}\text{ dip.} + cT \text{ (plus to alt. when sea is colder.)}$$

where $c = 11{\cdot}4''$ for height 0 feet

11·7	"	20
12·0	"	40
12·4	"	60
12·0	"	80
11·7	"	100

On this it may be remarked that the formula represents the consensus of upwards of 300 observations, giving due weight to separate results according to their distance from the first average.

A point on which any information would be welcomed is this. The term "$\frac{1}{20}$ dip." *changes sign suddenly* as T changes sign. Thus the function is *discontinuous*. I hope that this may be connected with a "critical angle" as in ordinary refraction of transparent substances, but I am unable to justify my conclusions by theory.

Again, I cannot believe that altitude does not affect the correction. But in all probability the disturbance takes place almost entirely in the line of sight from eye to horizon, and hardly at all in that from eye to Sun. Thus an effect of altitude would be masked by errors of observation.

It remains to add that *time* enters into the question. That is, the warming of the air after sunrise lags behind the warming of the mercury in thermometer. Thus a maximum or minimum effect occurs about 2 P.M.—in general it is a minimum.

But, on the contrary, the shift of horizon is plainly observable when a squall drifts up from windward. And (though this is not

directly applicable) the settling down of fog makes a marked difference, more than is accounted for by the usual corrections given by Bessel.

A provisional table is appended. It must be taken as including seconds of arc, not because these are reliable, but because only thus could advantage be taken of the analysis of many observations.

TENTATIVE TABLE

of correction to altitude due to shift of horizon caused by difference of temperature of sea and air (after applying to mean refraction the corrections for state of barometer and thermometer).

Sea colder, *plus* to alt.

Sea warmer, *minus* to alt.

Arguments :—Height of eye, feet

Difference of sea and air, degrees F.

Diff. Fahr.	Height of Eye, Feet. 0 or 140	20 or 120	40 or 100	60 or 80	Diff. Fahr.	Height of Eye, Feet. 0 or 140	20 or 120	40 or 100	60 or 80
°	′ ″	′ ″	′ ″	′ ″	°	′ ″	′ ″	′ ″	′ ″
1	11	25	31	35	7	1 20	1 35	1 43	1 50
2	23	36	43	48	8	1 31	1 47	1 55	2 2
3	34	48	55	1 0	9	1 43	2 0	2 7	2 15
4	46	1 0	1 7	1 13	10	1 54	2 12	2 19	2 27
5	57	1 11	1 19	1 25	20	3 48	4 6	4 19	4 31
6	1 8	1 23	1 31	1 37	30	5 42	6 3	6 19	6 35

Example :—Sea warmer by 23°, H.E. 30 feet

		′	″
for	20°	4	12
	3		52
		5	4 — to alt.

1906 *March* 15.

On Planetary Inversion. By F. J. M. Stratton, B.A.

I. *Introduction.*

§ 1. The question considered in the following paper is the influence of tidal friction in producing secular changes in the obliquities of the members of the solar system. This subject was suggested by some remarks of Professor W. H. Pickering in his

account of the discovery of *Phœbe*, the ninth satellite of *Saturn*.* Discussing the retrograde direction of its motion in its orbit, he offered as an explanation the theory that the planets originally rotated on their axes in a retrograde direction, and that under the influence of tidal friction their axes of rotation had gradually tilted over into their present positions. If, then, a satellite were thrown off in a very early stage of the planet's evolution it would commence moving in a retrograde direction round the planet. If the oblateness of the planet were very small, or the satellite at a considerable distance from the planet's centre, the plane of the orbit of the satellite would not follow the plane of the planet's equator as it tilted over, but would fall back into a stable position near the ecliptic—a term used in this paper for the plane of the planet's orbit. Such a satellite would remain of the retrograde type exemplified by *Phœbe*. If, however, the satellite were evolved in a later stage of the planet's development (after the planet had greatly contracted and become more oblate), the satellite would move in an orbit whose stable position was almost coincident with the planet's equator, and the satellite would follow the planet's equator. Most of the known satellites of the solar system fall into this class.

Professor Pickering urged in support of this view that the classical nebular hypothesis, according to which the planets were thrown off in the form of rings, required an initial retrograde rotation of the planet and not a direct one, as Laplace assumed. But of recent years Sir George Darwin,† Professor T. C. Chamberlin,‡ and Dr. F. R. Moulton § have adduced strong reasons for discarding the ring-theory, and it would seem that such confirmation as it would undoubtedly have given to this investigation must for the present be disregarded. Though apparently the classical form of the nebular hypothesis cannot now be accepted without considerable modifications I have here followed it in general as regards the history of the planetary sub-systems, and have assumed a planet to be a gradually contracting body, which from time to time may pass through a form of instability, resulting in the evolution of a satellite.

I have also assumed that the determining factor in producing secular changes in the obliquity of a planet has been tidal friction. A justification for this assumption may be found in a statement made by Adams ¶ that no secular alterations of a planet's obliquity can arise from the attraction of its satellites and the Sun. One reason for the further assumption of initial retrograde rotation is that it gives an explanation why the two outermost planets should have an obliquity greater than 90°. It

* *Annals of Harvard College Observatory*, vol. liii. No. III., "The Ninth Satellite of *Saturn*," W. H. Pickering.

† Presidential Address to the British Association, South Africa, 1905, p. 17.

‡ *Journal of Geology*, vol. viii.; and Carnegie Institution, Year Book, No. 3.

§ *Astrophysical Journal*, 1900 February and 1905 October.

¶ See p. 385.

does not seem that under any theory of initial direct rotation their obliquities could have increased past 90° to the values that they appear to have at present. "It must be admitted," Sir George Darwin has said,* "that the Uranian system points to the possibility of the existence of a primitive planet with either retrograde rotation or at least with a very large obliquity of equator." At the same time I should feel considerable hesitation in applying to the inner planets a theory based on the position of the satellites of *Uranus* and *Neptune*, were it not that the remarkable discovery of *Phœbe* seems to compel us to attribute to *Saturn* also a primitive obliquity greater than 90°. And if once the possibility of such a change in the obliquity is conceded in *Saturn's* case the further extension of the theory to the inner planets presents no great difficulty. I must admit, however, that the whole theory is of an extremely speculative nature; many serious difficulties still remain unsolved, such as the extension to heterogeneous planets of the theory of tides in a homogeneous, incompressible spheroid. If, therefore, I am betrayed in my paper into too dogmatic statements I hope it will be understood that they owe their emphatic form solely to a desire to avoid the continual use of the conditional mood. If I state as facts results indicated by the theory, it is not because the hazardous nature of the theory is not recognised, but because it becomes intolerable to continue to insist on the point throughout the whole paper. One word of defence should, perhaps, be added for the rather rough approximations employed from time to time. In treating a hypothesis which is certainly largely removed from the facts it does not seem necessary always to employ the methods of the most exact analysis. All that is required is to obtain the general conclusions to which the hypothesis leads.

§ 2. Leaving these general considerations on one side I proceed to discuss the paper in greater detail. Throughout I follow Sir George Darwin's theory of the action of the tides and I make free use of the results that he obtains in his series of papers in the *Philosophical Transactions* of the Royal Society.† The tides are regarded as a bodily deformation of the planet, which is supposed to be a homogeneous, incompressible, viscous spheroid.

* "On the Secular Changes in the Elements of the Orbit of a Satellite revolving about a Tidally Distorted Planet," *Phil. Trans.* part ii. 1880, p. 886.

† "On the Bodily Tides of Viscous and Semi-elastic Spheroids and on the Ocean Tides upon a Yielding Nucleus," *ibid.* part i. 1879.

"On the Precession of a Viscous Spheroid and on the Remote History of the Earth," *ibid.* part ii. 1879.

"On Problems connected with the Tides of a Viscous Spheroid," *ibid.* part ii. 1879.

"On the Secular Changes in the Elements of the Orbit of a Satellite revolving about a Tidally Distorted Planet," *ibid.* part ii. 1880.

"On the Tidal Friction of a Planet attended by several Satellites and on the Evolution of the Solar System," *ibid.* part ii. 1882.

These papers will hereafter be referred to as "Tides," "Precession," "Problems," "Orbits," and "Evolution" respectively.

Laplace has shown that, under certain conditions, compressibility does not affect the results to any great extent; * and Sir George Darwin has shown in "Evolution" that no serious error is involved in the hypothesis of homogeneity as opposed to heterogeneity, so long as only a surface layer of slight viscosity is affected. In the same paper he has shown that tidal friction can have but very slightly affected the dimensions of the planetary orbits. Hence I shall throughout consider the mean distances of the planets as having their present values. Further, I adopt Sir George Darwin's limitation in considering the eccentricities zero. In adapting his results to my hypothesis I shall of course be unable to reproduce all his reasoning, and I shall have to ask the reader, if unacquainted with his papers, to take my quotations from them as established.

In fitting this theory on to Sir George Darwin's investigations as to the tidal evolution of the Earth-Moon system I have to show that, starting with a planet unattended by a satellite, rotating in a retrograde direction and revolving about the Sun, it is possible to proceed to a state of affairs in which the planet in a highly viscous state rotates some 3,000 times in the course of one revolution about the Sun, and has an obliquity of about 11°. Part II. is therefore devoted to a discussion of the secular changes in the obliquity of a viscous spheroid due to the tidal action of one satellite (the Sun). This is practically the problem dealt with in "Precession," but it is here extended to the case where the obliquity is greater than 90°.

In Part III. I introduce a second satellite, small in mass compared with the planet and much nearer than the Sun, and I discuss the influence of the planet's tides on the inclination of the satellite and on the obliquity of the planet. In Part IV. I extend the last case to admit of several small satellites being present, and I make an application of the theory to the satellites of the solar system. In this part I extend the practical applications of the theory by a discussion of the past changes suggested by the theory in the obliquities of the planets and in the orbits of the satellites. Finally in Part V. I give a brief summary of the results obtained in the foregoing paper and of the general conclusions to which the theory points.

§ 3. I must now explain the notation, which, following Sir George Darwin, I shall use throughout the paper. The method employed is that of the disturbing function, changes in the elements fixing a body's position being obtained by differentiating the function with respect to certain of the other elements expressing the position of the disturbed body. Now we have to determine the perturbations of a satellite under the influence of tides raised by itself, and thus the elements of the satellite's path will enter the disturbing function in two ways, in the expression both of the distorted state of the planet and of the position of the satellite. It is only in this latter sense that we require the

* *Mécanique Céleste,* livre iv. ch. v.

function to be differentiated, and hence we make the following convention: the elements of the tide-raising satellite are to be unaccented letters, those of the disturbed satellite (or, if the effect of the planet is being considered, of the disturbing satellite) are to be accented; the differentiation is to be made with regard to the accented letters, and after the differentiation the two satellites may, if necessary, be made identical by dropping the accents, or they may be kept distinct.

The following are the symbols employed:—

t = the time.

The suffix $_0$ = the initial value of the symbol to which it is attached.

For the planet we have:

M = mass.

a = mean radius.

e = ellipticity of a meridian section.

w = density of the planet supposed homogeneous.

g' = mean gravity at its surface.

$$g = \frac{2}{5}\frac{g'}{a}.$$

n = angular velocity of diurnal rotation.

ψ = longitude of vernal equinox measured along the ecliptic—some fixed plane regarded as practically coincident with the planet's orbit—from a fixed point in the ecliptic.

i = obliquity of ecliptic.

χ = angle between a point fixed on the equator and the vernal equinox.

For the tide-raising satellite we have:

c = mean distance.

$$\xi = \left(\frac{c}{c_0}\right)^{\frac{1}{2}}.$$

Ω = mean motion.

j = inclination of orbit to ecliptic.

N = longitude of node.

ϵ = longitude of epoch.

m = mass.

ν = ratio of planet's mass to satellite's mass $= \dfrac{M}{m}$.

$$\tau = \frac{3\Omega^2}{2(1+\nu)}.$$

For the disturbed (or disturbing) satellite the same symbols apply, but accented.

Further, we have a quantity k such that $\frac{kn}{\xi}$ = the ratio of the moment of momentum of the planet's rotation to that of the orbital motion of planet and satellites round their common centre of inertia. If W is the disturbing function the equation giving the variation of the inclination of the satellite's orbit is

$$-\frac{dj}{dt}=\frac{k}{\xi}\left(\frac{1}{\sin j'}\frac{\partial W}{\partial N'}+\tan\tfrac{1}{2}j'\frac{\partial W}{\partial \epsilon'}\right)\quad\ldots\quad\ldots\quad(1)$$

The equation for the variation of the obliquity is

$$n\sin i\frac{di}{dt}=\cos i\frac{\partial W}{\partial \chi'}-\frac{\partial W}{\partial \psi'}\quad\ldots\quad\ldots\quad(2)$$

These two equations are quoted from "Orbits."

Before giving Professor Darwin's value for W several fresh definitions must be given. There are present in the disturbing function tides of seven distinct speeds* ($2n-2\Omega$, $2n$, $2n+2\Omega$ $n-2\Omega$, n, $n+2\Omega$, 2Ω), and the tides are retarded by different amounts and are of varying heights. The retardation of the phase of the tide is called its "lag," and its height is expressed as a fraction of the corresponding equilibrium tide in a perfectly fluid spheroid. The following table gives the symbols to be employed for the several tides :—

Tide.	Semi-diurnal. Slow.	Semi-diurnal. Sidereal.	Semi-diurnal. Fast.	Diurnal. Slow.	Diurnal. Sidereal.	Diurnal. Fast.	Fortnightly.
Speed	$2n-2\Omega$	$2n$	$2n+2\Omega$	$n-2\Omega$	n	$n+2\Omega$	2Ω
Height	F_1	F	F_2	G_1	G	G_2	H
Lag	$2f_1$	$2f$	$2f_2$	g_1	g †	g_2	$2h$

The heights and lags are connected by the following relations :—

$$\left.\begin{array}{r}F_1=\cos 2f_1\,;\ F=\cos 2f\,;\ F_2=\cos 2f_2\,;\ G_1=\cos g_1\,;\\ G=\cos g\,;\ G_2=\cos g_2\,;\ H=\cos 2h\\ \tan 2f_1=2(n-\Omega)/\sigma\,;\tan 2f=2n/\sigma\,;\tan 2f_2=2(n+\Omega)/\sigma\,;\\ \tan g_1=(n-2\Omega)/\sigma\,;\ \tan g=n/\sigma\,;\ \tan g_2=(n+2\Omega)/\sigma\,;\\ \tan 2h=2\Omega/\sigma\end{array}\right\}(3)$$

where $\sigma = 2g'\,a\,\omega/19v$.

v is the coefficient of viscosity of the tidally disturbed layer, and hence we may take f roughly as a measure of the viscosity

* The "speed" of a tide is the coefficient v of t in the trigonometrical term $\cos(vt+p)$ occurring in the expression for the tide's action.

† Note that this is not the same g as the one defined above, p. 378. As this g is an angle and always appears in a trigonometrical form there is no chance of confusion between the two g's.

of the planet; $f = 10^\circ$ represents a small viscosity, $f = 45^\circ$ an infinite one.

$$\left.\begin{array}{r}\text{Let now } \mathrm{P} = \cos\frac{i}{2},\ \mathrm{Q} = \sin\frac{i}{2},\ p = \cos\frac{j}{2},\ q = \sin\frac{j}{2} \\ \varpi = \mathrm{P}p - \mathrm{Q}q\, e^{\sqrt{-1}(\mathrm{N}-\psi)} = \mathrm{P}p - \mathrm{Q}q \text{ expi } \{\mathrm{N}-\psi\}\ ^{*} \\ k = \mathrm{Q}p + \mathrm{P}q \text{ expi } \{\mathrm{N}-\psi\} \\ \underline{\varpi} = \mathrm{P}p - \mathrm{Q}q \text{ expi } \{-(\mathrm{N}-\psi)\}\ \underline{k} = \mathrm{Q}p + \mathrm{P}q \text{ expi} \\ \{-(\mathrm{N}-\psi)\}\end{array}\right\} \quad . \ (4)$$

Then $\mathrm{W} = (\mathrm{W_I} + \mathrm{W_{II}} + \mathrm{W_{III}} + \mathrm{W_1} + \mathrm{W_2} + \mathrm{W_3} + \mathrm{W_0})$ consists of the seven following pairs of terms:—

$$\frac{g}{\tau\tau'}\mathrm{W_I} = \text{slow semi-diurnal term}$$
$$= \tfrac{1}{4}\mathrm{F_1}\varpi^4\underline{\varpi}'^4 \text{ expi } 2\{\chi - \chi' - (\epsilon - \epsilon') + \psi - \psi' - f_1\} + \ldots$$

$$\frac{g}{\tau\tau'}\mathrm{W_{II}} = \text{sidereal semi-diurnal term}$$
$$= \mathrm{F}\varpi^2\underline{k}^2\underline{\varpi}'^2k'^2 \text{ expi } 2(\chi - \chi' - f) + \ldots$$

$$\frac{g}{\tau\tau'}\mathrm{W_{III}} = \text{fast semi-diurnal term}$$
$$= \tfrac{1}{4}\mathrm{F_2}\underline{k}^4k'^4 \text{ expi } 2\ \{\chi - \chi' + (\epsilon - \epsilon') - (\psi - \psi') - f_2\} + \ldots$$

$$\frac{g}{\tau\tau'}\mathrm{W_1} = \text{slow diurnal term}$$
$$= \mathrm{G_1}\varpi^3k\underline{\varpi}'^3\underline{k}' \text{ expi } \{\chi - \chi' - 2(\epsilon - \epsilon') + 2(\psi - \psi') - g_1\} + \ldots$$

$$\frac{g}{\tau\tau'}\mathrm{W_2} = \text{sidereal diurnal term}$$
$$= \mathrm{G}(\varpi\underline{\varpi} - k\underline{k}(\varpi'\underline{\varpi}' - k'\underline{k}')[\varpi\underline{k\varpi}'k' \text{ expi } \{\chi - \chi' - g\} + \ldots]$$

$$\frac{g}{\tau\tau'}\mathrm{W_3} = \text{fast diurnal term}$$
$$= \mathrm{G_2}(\underline{\varpi}k^3\varpi'k'^3 \text{ expi } \{\chi - \chi' + 2(\epsilon - \epsilon') - 2(\psi - \psi') - g_2\} + \ldots$$

$$\frac{g}{\tau\tau'}\mathrm{W_0} = \text{fortnightly term}$$
$$= \tfrac{3}{2}(\tfrac{1}{3} - 2\varpi\underline{\varpi}k\underline{k})(\tfrac{1}{3} - 2\varpi'\underline{\varpi}'k'\underline{k}') + \tfrac{3}{2}\mathrm{H}\varpi^2\underline{k}^2\underline{\varpi}'^2k'^2 \text{ expi } 2\{\epsilon - \epsilon' - (\psi - \psi') - h\} + \ldots$$

The second term in each of the above expressions can be obtained from the first by exchanging ϖ with ϖ', $\underline{\varpi}$ with $\underline{\varpi}'$, k with k', and $\underline{k}$ with $\underline{k}'$, and also changing the sign of the exponential expression. This gives the disturbing function to be differentiated, as

* For convenience of printing we write expi for $e^{\sqrt{-1}}$. This abbreviation has been suggested by Professor Turner.

in equations (1) and (2), for the secular variations in the elements of the satellite or the planet.

II. *Secular Changes in the Obliquity of a Viscous Spheroid under the Tidal Action of One Satellite.*

§ 1. This problem has already been discussed by Sir George Darwin in "Precession," and we shall make use of the result he there obtains (p. 474) for the secular rate of variation of the obliquity.

We shall have then

$$\left.\begin{aligned}\frac{di}{dt}=\frac{\tau^2}{gn}\frac{1}{128}\sin i\{&[10\sin 4f_1-10\sin 4f_2+16\sin 2g_1-16\sin 2g_2-12\sin 4h]\\ &+\cos i[15\sin 4f_1-4\sin 4f+15\sin 4f_2+18\sin 2g_1-24\sin 2g+18\sin 2g_2]\\ &+\cos 2i[6\sin 4f_1-6\sin 4f_2+12\sin 4h]\\ &+\cos 3i[\sin 4f_1+4\sin 4f+\sin 4f_2-2\sin 2g_1-8\sin 2g-2\sin 2g_2]\}_1\end{aligned}\right\} \quad (5)$$

where $f, f_1, f_2, g, g_1, g_2, h$ are determined by equation (3) when some value is assumed for one of them. The extension of Sir George Darwin's work in this paper consists in two things. He deals with values of i from 0° to 90° only, while here i must be taken to vary between 0° and 180°. Again, he has not to consider the question of the variation in the viscosity, or rather in the angle $2f$, as the planet contracts from a nebulous mass and increases its rate of rotation. This point will first be briefly discussed.

If we consider the changes in the viscosity that accompany the evolution of the planet, we find that sufficient data are lacking to enable us to formulate any law on the subject. As will be seen later, the only planets in which the Sun's action on its own tides has been the determining factor throughout in producing changes of obliquity are *Mercury*, *Venus*, the Earth (before the birth of the Moon), and *Mars*. The obliquity of *Mercury* is unknown, that of *Venus* doubtful, different observers giving values as different as 37° and 0°; the obliquity of the Earth when revolving in a highly viscous state at the time of the Moon's birth was about 11°; the present obliquity of *Mars* is nearly 25°. A glance at the details given below will show that, starting with a retrograde rotation, tidal friction would eventually drive the axis of rotation over into a stable position where the obliquity lies somewhere between 90° and 0°. For all but viscosities so large that the semi-annual tide is of greater importance than the diurnal and semi-diurnal tides the stable value of the obliquity will be near 90°. The low obliquities of the Earth and *Mars* can only be obtained if we make the assumption that some such viscosities have obtained in their past history; in picking out a few cases for arithmetical investigation I have been guided rather by this idea than by any supposed law

connecting viscosity with density. The value of the results given lies chiefly in the illustration they afford of the general nature of the graphs for $\frac{di}{dt}$.

§ 2. The accompanying figure gives the form of the graph for $\frac{di}{dt}$ in the following cases :—

$n = 5\Omega$	$h = 10^\circ$	$f = 30^\circ\ 36'$
$n = 10$	$h = 11$	$f = 38\ \ 3$
$n = 20$	$h = 12\ 30$	$f = 41\ 58$
$n = 100$	$h = 15$	$f = 44\ 30\frac{1}{2}$
$n = 1,000$	$h = 20$	$f = 44\ 58$
$n = 10,000$	$h = 22\ 30$	$f = 44\ 59\frac{1}{4}$

From the figure we see fairly satisfactorily that for varying values of $\frac{n}{\Omega}$ and for different viscosities we may make $\frac{di}{dt}$ zero for any value of i we like between 0° and 90°; also, since in passing through this zero value $\frac{di}{dt}$ becomes negative as i increases, the obliquity will there have a stable value, but not at 0° nor at 180°. Starting, then, with a sphere of slight viscosity, with an obliquity of 180°, we shall have initially a decrease of obliquity, and in any case the obliquity will eventually become less than 90°. But as the sphere contracts its viscosity increases, and if it does so in such a way that the effect of the semi-annual tide steadily increases relatively to that of the diurnal and semi-diurnal tides, then, when $\frac{n}{\Omega}$ has attained a large value, the sphere will rotate as though almost rigid for these latter tides and the stable position of the obliquity will be a very small angle. If, however, after the planet reaches this position the viscosity still increases for the bodily tides, but an ocean of much smaller viscosity forms upon the surface, then the effect of the bodily tides may become negligible, and under the influence of the slightly viscous ocean tides the planet may gradually tilt over till it reaches a position of stability with a fairly high obliquity.

Thus we may conceive that *Mercury* has tilted over into a position of small obliquity and that it never had oceans of sufficient magnitude to tilt it back. *Venus* may or may not have been seriously affected by ocean tides after reaching a position of low obliquity under the influence of bodily tides. Here observation leaves it open for one to hold either view. The Earth has in its later history been affected by the presence of the Moon, and therefore it need not be considered in this section. *Mars* may never have tilted over so far as the Earth did, owing to its

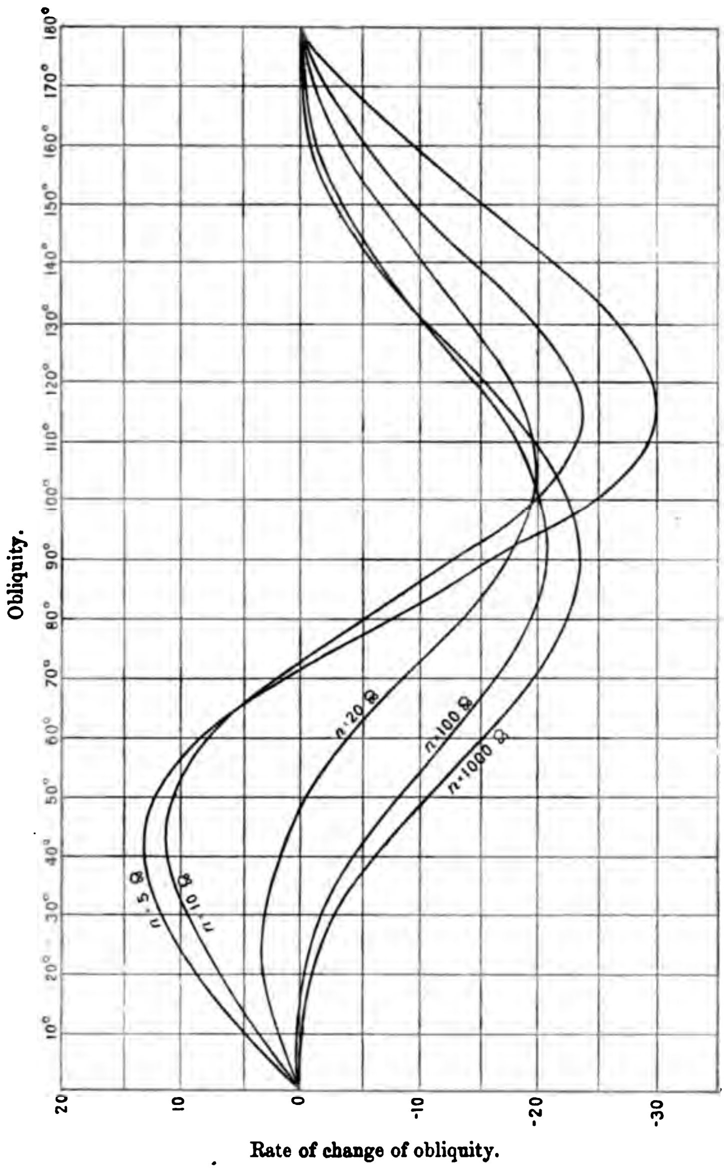


Diagram showing change of obliquity of a planet due to solar tides.

longer period of revolution, and it may be already on the way back, under the influence of ocean tides, to a position of stability with its axis of rotation almost in the plane of its orbit. The other planets will be considered in Part IV.

III. *The Tidal Action of Two Satellites.*

§ 1. When there are two satellites, one of which we distinguish as the Sun, setting up tides on a planet and acting on their own and each other's tides, we have to distinguish four sets of terms in the disturbing function which gives the perturbations of the planet and the satellite :—

(i) when the tide-raiser is the satellite and the disturber is the satellite,
(ii) when the tide-raiser is the Sun and the disturber is the satellite,
(iii) when the tide-raiser is the satellite and the disturber is the Sun,
(iv) when the tide-raiser is the Sun and the disturber is the Sun.

For perturbations in the planet all four sets of terms exist, but for perturbations in the satellite we alter "disturber" into "disturbed body," and notice that we have only to consider cases (i) and (ii).

Now let τ as defined on p. 378 refer to the satellite and let τ' refer to the Sun. Then, in considering the changes in the satellite's inclination given by equation (1), we derive from the disturbing function two sets of terms corresponding to cases (i) and (ii) above. These consist of functions of i and j of somewhat the same type as that given in equation (5).* But they have as coefficients the factors $\frac{k}{\xi}\frac{\tau^2}{g}$ and $\frac{k}{\xi}\frac{\tau\tau'}{g}$ respectively, and these factors are so small for all the satellites of the solar system as to render these terms in the disturbing function negligible compared with certain other terms yet to be mentioned.

For the disturbing function (†)

$$\Omega = \mathrm{K}\cos^2\gamma + \mathrm{K}'\cos^2\gamma'$$

where γ, γ' are the angles made by the satellite's orbit with the planet's orbit and equator respectively, from which, according to the ordinary dynamical theory, the secular position of the satellite's orbit (*i.e.* the satellite's proper plane, round the pole of which the pole of the orbit describes an ellipse) is derived, gives

* The exact form of the expression derived from case (i) is given in "Orbits," pp. 740, 746.

† See Tisserand, *Mécanique Céleste*, vol. iv. ch. vi. s. 37.

some secular terms in the expression for $\frac{dj}{dt}$. These give the following equation for the position of the satellite's proper plane:

$$K \sin 2j = K' \sin 2(i-j),$$

or, as it may be written,

$$\tan 2(i-j) = \frac{K \sin 2i}{K' + K \cos 2i}, \quad \text{or } \tan 2j = \frac{K' \sin 2i}{K + K' \cos 2i}.$$

The addition to the disturbing function of the tidal terms mentioned in the preceding paragraph will not sensibly affect the equilibrium position of the satellite's orbit. For if $(i-j)$ is small compared with i—i.e. if $\frac{K}{K'}$ is small—then the numerator of the above expression for $\tan 2(i-j)$ should be diminished by a quantity of the order of $\left(\frac{a}{c}\right)^5 K \sin 2i$, and the denominator increased by a quantity of the order of $\frac{a^3}{ec_s^3} K'$, where a is the planet's mean radius, c, c_s the satellite's and the Sun's mean distances, and e is the planet's oblateness. These alterations will produce a quite insensible diminution in the angle $(i-j)$; in the other case, where $\frac{K'}{K}$ is near unity or small, the additional terms due to tidal action are still less sensible than in the above case. In all cases, then, tidal action may be neglected in finding the secular position of a satellite's orbit, which is found by the usual gravitational methods; it is different, however, when we consider the obliquity of a planet.

§ 2. Adams has shown * that the obliquity of a planet is only altered by periodic terms under the attraction of its satellites and the Sun, so that we must look to other causes for secular changes in the obliquity. This being the case it seems fair to assume that the determining factor in the obliquity of a planet is tidal friction, and that is, in fact, the fundamental assumption on which this whole paper is based. For perturbations in the planet we have all the four sets of terms arising from the cases discussed on p. 384; as they have respectively the coefficients $\frac{\tau^2}{g}, \frac{\tau\tau_s}{g}, \frac{\tau\tau_s}{g}, \frac{\tau_s^2}{g}$ we see that we need take into consideration the tidal effect of the satellite, only when $\frac{\tau}{\tau_s}$ is large or near unity. When $\frac{\tau}{\tau_s}$ is small the planet moves as though under solar tidal friction alone, in the manner discussed in Part II. Now, except for the Moon, in all cases where $\frac{\tau}{\tau_s}$ is finite or large we have $\frac{K'}{K}$ also

* *Observatory*, 1886 April.

large, and the satellite's orbit has a secular position which passes through the node of the planet's equator on the planet's orbit, and is inclined at a very small angle to the planet's equator. That is to say, that in all cases where we have to take into consideration the presence of a second satellite in discussing the change in a planet's obliquity we may take $(i-j)$ small compared with i, and $N-\psi = 180°$,* for N, ψ are the longitudes on the planet's orbit of the vernal equinox and the ascending node of the satellite's orbit.

In this case $\quad \text{expi}\,(N-\psi) = \text{expi}\{-(N-\psi)\} = -1$;

therefore for the satellite

$$\varpi = Pp - Qq\,\text{expi}\,(N-\psi) = \cos\frac{i}{2}\cos\frac{j}{2} + \sin\frac{i}{2}\sin\frac{j}{2}$$
$$= \cos\tfrac{1}{2}(i-j) = \underline{\varpi}$$
$$k = Qp + Pq\,\text{expi}\,(N-\psi) = \sin\frac{i}{2}\cos\frac{j}{2} - \cos\frac{i}{2}\sin\frac{j}{2}$$
$$= \sin\tfrac{1}{2}(i-j) = \underline{k},$$

and therefore, since $(i-j)$ is small, k is small, and it is easier in discussing $\frac{di}{dt}$ to keep k and ϖ in our formulæ to the very last and then to substitute. Taking then the various terms of W from p. 380, and substituting in the equation (2), which we wrote in the form

$$n\frac{di}{dt} = \frac{P^2-Q^2}{2PQ}\frac{\partial W}{\partial \chi'} - \frac{1}{2PQ}\frac{\partial W}{\partial \psi'},$$

we derive sets of terms from the four cases as follows :—

Case (i).—Since ψ' occurs only with N' in the ϖ's and k's, and with ϵ' in the other exponential factors, and since N', ϵ' only occur in the connection $N'-\psi'$, $\epsilon'-\psi'$ it really facilitates the finding of the result to write :

$$\frac{\partial W}{\partial \psi'} = -\left(\frac{\partial W}{\partial N'} + \frac{\partial W}{\partial \epsilon'}\right)$$

For the sake of brevity in the following work we shall drop the factor $\frac{3}{2}\frac{r^2}{g}$ and let ϵ, N, ϵ', N' stand for $\epsilon-\psi$, $N-\psi$, $\epsilon'-\psi'$, $N'-\psi'$ respectively, and also omit the second terms in W_I, &c. After differentiation we can drop the accents, as the tide-raiser and disturber are the same body. In this case k', $\underline{k}'$ have the same value as k, $\underline{k}$ or $\sin\frac{1}{2}(i-j)$, while ϖ', $\underline{\varpi}'$ have the same value as ϖ, $\underline{\varpi}$ or $\cos\frac{1}{2}(i-j)$. Since we are only seeking the first approximation we shall only discuss the terms in W, which can give us terms of the lowest possible order, namely, the first, in

* See p. 389.

k, k'; the next lowest order occurring is the third, and terms of that order may safely be neglected.

Now

$$W_I = \tfrac{1}{4}F_1(\varpi^4\underline{\varpi}'^4 \operatorname{expi} 2\{\chi-\chi'-(\epsilon-\epsilon')-f_1\} + \ldots$$

$$\therefore \frac{\partial W_I}{\partial N'} = \sqrt{-1}\,qQF_1(-\varpi^7 \operatorname{expi}(-2f_1)+\varpi^7 \operatorname{expi} 2f_1)$$

$$\frac{\partial W_I}{\partial \epsilon'} = \frac{\sqrt{-1}}{1} F_1(\varpi^8 \operatorname{expi}(-2f_1)-\varpi^8 \operatorname{expi} 2f_1)$$

$$\frac{\partial W_I}{\partial \chi'} = -\frac{\partial W_I}{\partial \epsilon'}$$

$$n\frac{di_I}{dt} = \frac{1}{2PQ}\left\{2Q^2\frac{\partial W_I}{\partial \epsilon'}+\frac{\partial W_I}{\partial N'}\right\}$$

$$= -F_1 \sin 2f_1\varpi^7\left(\frac{q}{P}-\frac{Q}{P}\varpi\right)$$

$$= F_1 \sin 2f_1\varpi^7 k.$$

W_{II} must give us as the largest possible term one in k^3; it is therefore to be neglected here, as also is W_{III}, which gives terms of the seventh order in k.

$$W_1 = G_1(\varpi^3\underline{k}\underline{\varpi}'^3k' \operatorname{expi}\{\chi-\chi'-2(\epsilon-\epsilon')-g_1\} + \ldots$$

$$\therefore \frac{\partial W_1}{\partial N'} = 2G_1 \sin g_1\varpi^5 k(-3kqQ+\varpi qP)$$

$$\frac{\partial W_1}{\partial \epsilon'} = 4G_1 \sin g_1\varpi^6 k^2$$

$$\frac{\partial W_1}{\partial \chi'} = -\tfrac{1}{2}\frac{\partial W_1}{\partial \epsilon'}$$

and

$$n\frac{di_1}{dt} = \frac{1}{2PQ}\left\{\frac{\partial W_1}{\partial N'}+\tfrac{1}{2}\frac{\partial W_1}{\partial \epsilon'}(3Q^2+P^2)\right\}$$

$$= -G_1 \sin g_1\varpi^5 k\left\{\frac{3k}{P}(q-Q\varpi)-\frac{\varpi}{Q}(q+Pk)\right\}$$

$$= G_1 \sin g_1\varpi^5 k(3k^2+\varpi^2)$$

$$W_2 = G(\varpi\underline{\varpi}-k\underline{k})(\varpi'\underline{\varpi}'-k'\underline{k}')(\varpi\underline{k}\,\underline{\varpi}'k' \operatorname{expi}\{\chi-\chi'-g\} + \ldots$$

$$\frac{\partial W_2}{\partial N'} = 2G \sin g\,\varpi k(\varpi^2-k^2)^2(-kqQ-\varpi qP)$$

$$\frac{\partial W_2}{\partial \epsilon'} = 0$$

$$\frac{\partial W_2}{\partial \chi'} = -2G \sin g\varpi^2 k^2(\varpi^2-k^2)^2$$

$$\therefore n\frac{di_2}{dt} = -G \sin g\varpi k(\varpi^2-k^2)^2\{pq+\varpi k(P^2-Q^2)\}\frac{1}{PQ}$$

$$= -G \sin g\varpi k(\varpi^2-k^2)^3.$$

W_3 may be neglected for the same reason as W_{III}, and so too may W_0, for the terms of lowest order derived from it are of the third order in k.

Hence, retaining only the terms of the lowest order in k and restoring the omitted factor, we obtain from this case :—

$$n\frac{di_{(i)}}{dt} = \frac{\tau^2}{g}k\varpi^7(F_1 \sin 2f_1 + G_1 \sin g_1 - G \sin g)$$

$$= \frac{\tau^2}{g}\sin \tfrac{1}{2}(i-j)(F_1 \sin 2f_1 + G_1 \sin g_1 - G \sin g).$$

Case (*ii*).—In this case only W_{II}, W_2, W_0 can give secular terms in $\frac{di}{dt}$: here ϖ', k', $\underline{\varpi}'$, $\underline{k}'$ have the same value as in case (i), while

$$\varpi = \underline{\varpi} = \cos \tfrac{1}{2}i$$
$$k = \underline{k} = \sin \tfrac{1}{2}i.$$

The term of highest order of magnitude is the term independent of k' arising from W_2, and that is the only term we shall consider here. It gives :—

$$n\frac{di_{(ii)}}{dt} = -\frac{\tau\tau_s}{g}G \sin g\varpi k(\varpi^2 - k^2)(\varpi'^2 - k'^2)\frac{pq}{PQ}$$

$$= -\frac{\tau\tau_s}{g}G \sin g \cos\frac{i}{2}\sin\frac{i}{2}\cos i$$

$$= -\tfrac{1}{4}\frac{\tau\tau_s}{g}G \sin g \sin 2i.$$

Case (*iii*).—Here we have

$$\varpi = \underline{\varpi} = \cos \tfrac{1}{2}(i-j) \qquad \varpi' = \underline{\varpi}' = \cos \tfrac{1}{2}i$$
$$k = \underline{k} = \sin \tfrac{1}{2}(i-j) \qquad k' = \underline{k}' = \sin \tfrac{1}{2}i.$$

Hence, since the coefficient is the same $\left(\frac{\tau\tau_s}{g}\right)$ as in the previous case we need only consider terms independent of k. Since no such term arises from either W_{II}, W_2, or W_0, the only three parts of W which can give secular terms in this case, $\frac{di_{(iii)}}{dt}$, is negligible compared with $\frac{di_{(ii)}}{dt}$.

Case (*iv*) is the case dealt with in Part II., and the result obtained is given in equation (5).

We may greatly simplify the final expression for $\frac{di}{dt}$ by writing $f = f_1 = f_2$, $g = g_1 = g_2$ throughout. For in the only

case where $\frac{n}{\Omega}$ is moderately small, so that the approximation might make a sensible difference, the factor $\sin(i-j)$ is so small as to render the term altogether negligible.

We obtain then for $\frac{di}{dt}$ in the presence of two satellites, one of which is the Sun, the equation

$$\left.\begin{aligned} 2gn\frac{di}{dt} &= \tau^2 \sin\tfrac{1}{2}(i-j)\sin 4f - \tfrac{1}{4}\tau\tau_s \sin 2i \sin 2g \\ &+ \frac{\tau_s^2}{64}\sin i\{-12\sin 4h + \cos i(26\sin 4f + 12\sin 2g) \\ &\quad +\cos 2i\,.\,12\sin 4h + \cos 3i(6\sin 4f - 12\sin 2g)\} \end{aligned}\right\}\ldots \quad (6)$$

There is one correction to the above result which seems well worth noting. We have tacitly assumed that, because $(N-\psi)$ oscillates through a value $180°$, we may take 0 and -1 as the mean values of $\sin(N-\psi)$ and $\cos(N-\psi)$ respectively. This is of course not exact for $\cos(N-\psi)$, since its deviations from -1 are always of the same sign, and we must take as its mean value $(-1+\eta)$. In this case we must write

$$\varpi = \cos\tfrac{1}{2}(i-j) - \eta\sin\frac{i}{2}\sin\frac{j}{2} = \underline{\varpi}$$

$$k = \sin\tfrac{1}{2}(i-j) + \eta\cos\frac{i}{2}\sin\frac{j}{2} = \underline{k}.$$

Then retaining the terms in η of the first order from ϖ, $\underline{\varpi}$, k, $\underline{k}$ we have the following corrections to make: In case (i) the factor $\sin\frac{1}{2}(i-j)$ in the expression for $n\frac{di_{(1)}}{dt}$ is to be replaced by $\left(\sin\frac{1}{2}(i-j) + \eta\cos\frac{i}{2}\sin\frac{j}{2}\right)$. In case (ii). $\left(1-2\eta\sin\frac{i}{2}\,.\,\sin\frac{j}{2}\right)$ is to be written for 1. The former correction is sensible for many of the satellites of the solar system, though it does not affect the nature of the results; the latter correction is insensible. The total effect of this correction is a slight increase of the direct as opposed to the cross terms. With these corrections equation (6) should read

$$\left.\begin{aligned} 2gn\frac{di}{dt} &= \tau^2\left\{\sin\tfrac{1}{2}(i-j) + \eta\cos\frac{i}{2}\sin\frac{j}{2}\right\}\sin 4f \\ &\quad -\tfrac{1}{4}\tau\tau_s\left\{1-2\eta\sin\frac{i}{2}\sin\frac{j}{2}\right\}\sin 2i\sin 2g + \frac{\tau_s^2}{64}\sin i \\ &\left\{\begin{aligned} &-12\sin 4h + \cos i(26\sin 4f + 12\sin 2g) \\ &+\cos 2i\,.\,12\sin 4h + \cos 3i(6\sin 4f - 12\sin 2g) \end{aligned}\right\} \end{aligned}\right\} \quad 6\,(a)$$

For practical applications it becomes necessary to extend this

result so as to include the case of several small satellites; that is done in the following part.

IV. *Extension to the Case where several Small Satellites are Present.*

§ 1. The result given in equation (6) may be easily modified so as to give the value for $\frac{di}{dt}$ in the presence of several satellites. The terms arising from case (i) will be obtained by a simple summation $\Sigma_r \tau_r^2 \sin \frac{1}{2}(i-j_r) \sin 4f$, where r is a suffix denoting one of the satellites. If we consider the mutual action of two satellites (r and p) we obtain from cases (ii) and (iii), replacing τ_s by τ_p, $-\tau_r\tau_p \sin \frac{1}{2}(i-j_r) \sin 2g$, and $-\tau_r\tau_p \sin \frac{1}{2}(i-j_p) \sin 2g$. The action of the satellites on the solar tides is $-\frac{1}{4}\Sigma_r \tau_r \tau_s \sin 2i \sin 2g$, obtained by a simple summation from the previous result. As before, the action of the Sun on the satellite's tides is negligible in comparison. The action of the Sun on its own tides is unaffected, and we get eventually, if r, p signify any two of the m satellites of a planetary sub-system,

$$\left.\begin{aligned} 2gn\frac{di}{dt} &= \sum_{r=1}^{r=m} \tau_r^2 \sin \tfrac{1}{2}(i-j_r) \sin 4f - \sum_{r=1}^{r=m} \sum_{\substack{p=1 \\ r\neq p}}^{p=m} \tau_r\tau_p \sin \tfrac{1}{2}(i-j_r) \sin 2g \\ &\quad -\tfrac{1}{4}\sum_{r=1}^{r=m} \tau_r\tau_s \sin 2i \sin 2g + \frac{\tau_s^2}{64} \sin i\{-12 \sin 4h + \cos i(26 \sin 4f \\ &\qquad + 12 \sin 2g) + \cos 2i \,.\, 12 \sin 4h + \cos 3i(6 \sin 4f - 12 \sin 2g)\} \end{aligned}\right\} \ldots \quad (7)$$

Or if we allow for the correction discussed at the end of the previous Part, this equation should read

$$\left.\begin{aligned} 2gn\frac{di}{dt} &= \sum_{r=1}^{r=m} \tau_r^2 \left(\sin \tfrac{1}{2}(i-j_r) + \eta_r \cos \frac{i}{2} \sin \frac{j_r}{2}\right) \sin 4f \\ &\quad - \sum_{r=1}^{r=m} \sum_{\substack{p=1 \\ r\neq p}}^{p=m} \tau_r\tau_p \left(\sin \tfrac{1}{2}(i-j_r) + \eta_r \cos \frac{i}{2} \sin \frac{j_r}{2}\right) \sin 2g \\ &\quad -\tfrac{1}{4}\sum_{r=1}^{r=m} \tau_r\tau_s \sin 2i\left(1 - 2\eta_r \sin \frac{i}{2} \sin \frac{j_r}{2}\right) \sin 2g + \frac{\tau_s^2}{64} \sin i\{-12 \sin 4h \\ &\quad + \cos i(26 \sin 4f + 12 \sin 2g) + \cos 2i \,.\, 12 \sin 4h + \cos 3i\,(6 \sin 4f \\ &\qquad - 12 \sin 2g)\} \end{aligned}\right\} \quad 7\,(a)$$

§ 2. We proceed to apply this result to the different members of the solar system. *Mercury* and *Venus* have no satellites and they have therefore been already dealt with in Part II. The Earth-Moon system, differing as it does essentially from the other planetary sub-systems, has been already dealt with by Sir George Darwin in "Orbits." The satellites of *Mars* are so very small that for them $\frac{\tau}{\tau_s}$ is small. In fact, estimating their masses on the assumption that they are of the same density as the

satellite of known mass nearest to them in size, *Mimas*, we have the following approximate table :

Satellite.	Mass in Terms of Primary.	$\frac{\tau}{\tau_s}$.
Deimos	·000000001	$\frac{1}{17}$
Phobos	·0000000003	$\frac{1}{11000}$

Thus the cross terms with the Sun are small compared with the purely solar terms, being equivalent to a reduction of the solar term in (7) $\frac{\tau_s^2}{64}$ 12 sin $2g$ sin i cos i to $\frac{\tau_s^2}{64}$ 10 sin $2g$ sin i cos i. The terms arising from the action of the satellites on each other's tides are negligibly small ; for we have in their case an additional factor, sin $(i-j_r)$, which is not large enough to be sensible to observation. *Mars* will move then almost as if unattended by satellites, in the manner indicated in Part II. The position of equilibrium in its case will be with a somewhat smaller obliquity than if no satellites were present.

We proceed to the consideration of the Jovian system. The table corresponding to this system has been compiled from Professor Young's data * and from Tisserand.†

Satellite.	$\frac{\tau}{\tau_s}$.	$i-j$.
Jupiter V.	Very small	Assumed negligible
Io	103	10″
Europa	35	1′ 7″
Ganymede	32	4′ 38″
Callisto	2·9	24′ 12″

while i is taken as 3° 5′.

We may neglect *Jupiter* VI. and VII. They are so small that their $\frac{\tau}{\tau_s}$ is bound to be very small, and they will have no influence on the motion of the planet's axis. We may note that the key to their high inclination does not seem to lie in tidal friction.‡

* *Manual of Astronomy*, Tables I. and II. pp. 583–5.

† *Mécanique Céleste*, vol. iv. p. 62.

‡ "Professor W. H. Pickering has indeed suggested that his theory does account for the high obliquities of *Jupiter* VI. and VII., the planet having left them behind as it tilted over into its present position. Owing, however, to the fact that secular alterations in the positions of the satellites' orbits are produced far more rapidly than in the planet's obliquity, it is hardly possible that satellites can have been left behind in the way suggested. The fixed plane about which a satellite's orbit oscillates will always lie between the planet's orbit and the planet's equator, and the most that the change in the planet's obliquity could do would be possibly to increase the amplitude of

Substituting in (7) we obtain for *Jupiter* :

$$\frac{2gn}{\tau_s^2}\frac{di}{dt} = 1{\cdot}2 \sin 4f - 5{\cdot}7 \sin 2g - 4{\cdot}6 \sin 2g + ({\cdot}02 \sin 4f + {\cdot}0001 \sin 2g - {\cdot}00006 \sin 4h) \quad \ldots \quad \ldots \quad (8)$$

The additional terms on the right-hand side of this equation due to the correction allowed for in 7 (*a*) are certainly less than

$$+{\cdot}53 \sin 4f - 2{\cdot}17 \sin 2g.$$

In any case, then, the predominant terms are those arising from the cross-action of the satellites on each other's and on the solar tides, and they cause the planet's equator to sink steadily down into the ecliptic.

In a similar way we derive from data given in Struve's *Memoir* * the following table for *Saturn's* system :

Satellite.	$\frac{\tau}{\tau_s}$.	$i-j$.
Mimas...	9·58	0
Enceladus	15·4	0
Tethys...	35·8	0
Dione	28·8	0
Rhea	22·7	2′·79
Titan	96·8	37′·2

while $i = 26° \ 49'$.

Struve does not give the masses of *Hyperion* and *Iapetus*, but if we use Professor Pickering's photometric measurements † of them and of *Phœbe* as some indication of their diameters, and thence obtain their masses by comparison with satellites of about the same size, we obtain for them the following results :

Satellite.	$\frac{\tau}{\tau_s}$.
Hyperion	·005
Iapetus	·015
Phœbe	·00001

It seems, then, safe to omit these three satellites in considering

the oscillations about this fixed plane. This does not seem a sufficient explanation for the phenomenon in question, and some other cause, such as the close coincidence in size of the orbits, must apparently be sought to account for it."

* *Publications de l'Observatoire Central Nicolas*, vol. xi., "Beobachtungen der Saturnstrabanten," Hermann Struve.

† *Annals of the Harvard College Observatory*, vol. xi. p. 269.

changes in the planet's obliquity, and we obtain from (7) for *Saturn*:

$$\frac{2gn}{\tau_s^2}\frac{di}{dt}=51\sin 4f-61\sin 2g-42\sin 2g$$
$$+(\cdot 17\sin 4f+\cdot 03\sin 2g-\cdot 03\sin 4h) \quad \ldots \quad (9)$$

The additional terms due to the correction already noted have as an outside value $+0\cdot 36\sin 4f-2\cdot 14\sin 2g$.

Here again, then, the cross terms prevail and the planet's equator is being slowly driven down into the ecliptic. For *Saturn* and *Jupiter* alike this result seems independent of the viscosity assumed for the planet.

In extending the theory to the systems of *Uranus* and *Neptune* we are handicapped by lack of exact knowledge of the masses of the satellites and of the obliquities of the planets. Using the data as to the satellites' diameters given by Professor Young, and the same assumptions as before as to their densities we obtain the following results:—

Planet.	Satellite.	Mass in Terms of Primary.	$\frac{\tau}{\tau_s}$.
Uranus	Ariel	·0000003	42
	Umbriel	·00000014	8
	Titania	·000009	110
	Oberon...	·0000016	8
Neptune	Lassell's satellite ...	·0004	40,00

A difficulty arises if we try to get some idea of the positions of the equators of these planets, or rather of the secular values of $(i-j_r)$ for their various satellites. For the positions of the equators have not been determined by observations, and the satellites have not yet been observed long enough with sufficient accuracy to enable one to deduce the secular values of their inclinations with any degree of certainty; and naturally the obliquity and oblateness of these planets cannot yet be derived by theoretical means from the motions of their satellites. In view of the great distances of these planets from the Sun it seems tolerably safe to assume a negligibly small value of $(i-j_r)$ for their satellites. In the case of *Uranus* the most likely assumption is that the predominant term is the one arising from the action of the Sun on the satellite's tides; if this is so, then at present the obliquity is increasing from 90° towards 180°. In the case of *Neptune's* satellite we know that η is fairly large, and considering this in conjunction with the large value of $\frac{\tau}{\tau_s}$ we derive from 7 (*a*) with a considerable amount of certainty the conclusion that the obliquity of *Neptune* is at present also increasing towards 180°.

§ 3. (*a*.) We may now inquire in greater detail what this theory points to as the probable past history of the outer

planetary system. With regard to *Jupiter* it requires that when the satellites were first evolved solar tidal friction had already reduced the obliquity below 90°. For otherwise *Jupiter's* obliquity, instead of decreasing, would have increased from 90° and would at present be nearly 180°; and it does not seem possible that *Jupiter* VI. and VII. would have obliquities less than 90° at present, if they had been evolved while *Jupiter* had an obliquity greater than 90°. For *Saturn*, on the other hand, it seems necessary that *Phœbe* should have been evolved while the obliquity was still greater than 90°; possible that *Iapetus* and *Hyperion* were also evolved then, and impossible for *Titan* and the inner satellites to have been existing then. In that case the equation $K \sin 2j = K' \sin 2(i-j)$ connecting i and j would have led to the following state of affairs: When *Phœbe* was evolved its orbit would gradually move down to the ecliptic, as for it $\frac{K}{K'}$ is large. In the case of *Iapetus* $\left(\frac{K}{K'}\right.$ near and rather less than unity$\left.\right)$ the orbit would move from the planet's equator down to the ecliptic through an angle certainly less than $(180°-j)$. *Hyperion* would remain near *Saturn's* equator. As *Saturn's* axis slowly moved, under the influence of the solar tides and practically undisturbed by these three satellites, into the plane of *Saturn's* orbit round the Sun, *Phœbe* would fall more and more closely down to the ecliptic, while *Iapetus* would fall back upon the planet's equator. For only thus could the equation $K \sin 2j = K' \sin 2(i-j)$, $(K \neq K')$ be satisfied for $i = 90°$. *Hyperion* and *Iapetus* then would follow *Saturn's* equator over, while *Phœbe* would settle down with an obliquity near 180°. It is necessary that *Titan* and the other satellites should not be evolved with $i > 90°$, for in that case the cross term given by the action of the Sun on their tides would have been the predominant term, and *Saturn* would have moved down to an obliquity of 180° instead of one of 0°.

The case of *Uranus* seems to require that its satellites were evolved while the planet had an obliquity greater than 90° and less than its present value of 97° 51′. For the expression for $\frac{di}{dt}$ consists of two parts. One part, due to the cross terms, varying with $-\sin 2i$ and driving the obliquity away from 90°, is at present apparently the most important. The other, or solar, part tending to diminish the obliquity, decreases in value as i approaches 90°, but not so rapidly as $\sin 2i$ and not to the value zero. Since the first part prevails now and $i > 90°$, the obliquity can never, since the evolution of the satellites, have been near enough to 90° for the solar part to have been predominant, for then the obliquity would have become less than 90° and have remained so. And, since the obliquity is at present increasing, the satellites must have been evolved while the planet had an obliquity greater than 90° and less than its present value.

Neptune's one satellite too must have been evolved while *Neptune* had an obliquity greater than 90° for it to have ever reached its present position. At present, by its action on its own tides, it appears to be driving *Neptune* towards a position with an obliquity of 180°.

This theory accords well with Sir George Darwin's view * that the outer planets should evolve their satellites at an earlier period in their evolution than the inner ones. But it leaves us with a serious difficulty with regard to time, a difficulty which it is impossible to face properly. For with elements of uncertainty arising from the changing viscosity, density, and rotation period of the planet, with further complications of an unknown nature springing from the birth of a satellite and from an inability to settle at what period in the planet's evolution the satellite's tides will rise into importance, and with the greatest unknown factor remaining in the effects of heterogeneity, any results that might be obtained by integration would have very little value and would form a very inadequate return for the toil and labour involved.

Nevertheless it seems advisable to consider several points closely connected with the time difficulty and more open to examination. For instance, the question arises how far, if the planets tilted over under the influence of tides raised by the Sun, the dimensions of their orbits would be simultaneously altered. From "Evolution" (p. 534) we see that the rotational momentum of any planetary system is so minute compared with its orbital momentum round the Sun, that even the complete tilting over of a planet due to solar tidal friction would not require any appreciable compensating change in its mean distance from the Sun to conserve the angular momentum of the system. A finite change of tilt of the planet's equator is possible with only an extremely small alteration in the planet's mean distance. This is confirmed by a comparison of the value of $\frac{di}{dt}$ with the value of $\frac{1}{c}\frac{dc}{dt}$ derived from "Orbits," equation (70). This shows that for changes of obliquity in the solar system caused by tides set up in the planets we may consider the dimensions of the planets' orbits as fixed.† This conclusion is not affected when we consider the

* "Evolution," p. 532.

† Omitting a variable factor, a function of i, $\frac{1}{c}\frac{dc}{dt}$ is of the same order as $\frac{di}{dt}$ (expressed in circular measure) multiplied by

$$\left\{\frac{\text{the orbital momentum of the planet}}{\text{the rotational momentum of the Sun}} \times \frac{\text{rate of rotation of the Sun}}{\text{rate of rotation of the planet}} \times \left(\frac{\text{radius of planet}}{\text{radius of Sun}}\right)^2 \times \left(\frac{\text{mass of planet}}{\text{mass of Sun}}\right)^2\right\}.$$

At present for the solar system the greatest value of the above expression is about $\frac{1}{200,000,000}$, and it does not seem likely that it has been much greater for any of the planets in the past.

similar effects caused by tides in the Sun; for so long as the viscosities are small these tides will only give rise to terms in $\frac{dc}{dt}$ negligible compared with those already considered.

Taking the constancy of the mean axes of the planets as established as far as this investigation is concerned, we will now compare the relative size of the couples which the Sun exercises upon the various planets, or rather of the resulting rates of change of obliquity. Omitting the variable factor, arising from the function of i, which is always present in the expression for $\frac{di}{dt}$, and taking the relative rate to be represented by $\frac{r^2}{gn}\sin 4f$, further making the arbitrary assumption that the viscosity (supposed small) varies with the density, we obtain the following table:—

Planet.	Rate of Change of Obliquity.
Mercury	222,000,000
Venus	1,440,000
Earth	140,000
Mars	77,200
Jupiter	1
Saturn	$\frac{1}{7}$
Uranus	$\frac{1}{130}$
Neptune	$\frac{1}{4200}$

If, then, tidal friction is in the main responsible for the present obliquities of the planets we are forced by the figures of the above table to one of the following assumptions. Either the outer planets were evolved at periods long anterior to the inner ones, and therefore are relatively more advanced, or else they had initially very different obliquities, the outer ones being more removed from the natural obliquity of 180° than the inner one;* a third alternative remains, that the inner planets have spent long periods in or near positions of equilibrium, where they have been moving very slowly or not at all; the result of this would be that they would fall behind the positions which, by comparison with the steadily moving outer planets, they should have reached. Possibly the present state of affairs is due to a combination of these three causes.

There remains one other difficulty in connection with the time required for the working out of the theory, and that difficulty, though an almost necessary accompaniment of any such theory, would be alone sufficient to prevent one from urging its acceptance on dynamical grounds alone. It does not appear

* This might well be the case in the spiral nebular theory outlined by Professor Moulton (*Astrophysical Journal*, 1905 November).

that, for such enormous periods of time as we are here concerned with, our ordinary dynamical equations are of sufficient exactitude to prevent the entrance of some unknown factors, which may profoundly modify the course of the evolution of the system. This difficulty must be regarded as an additional cause for receiving the theory with all reserve.

§ 3. (*b.*) We have seen that the mean distances of the planets from the Sun may be regarded as unaffected by tidal friction. It is of interest to discuss how far, as hinted in "Evolution," and so far tacitly assumed in this paper, the same holds good for the orbits of the satellites. A comparison of the value of $\frac{1}{c}\frac{dc}{dt}$ for a satellite* and of $\frac{di}{dt}$ for a planet shows at once that so long as the satellite remains tidally effective (*i.e.* so long as r_r is of the same order as r_s) the satellite's orbit will increase very largely, while i will only vary by an extremely minute quantity. In fact, while a satellite's mean distance may be enlarged by tidal friction so much that the satellite's tides become negligible compared with the Sun's tides, the planet will not appreciably alter its obliquity.† The result of this seems to be that the action of the satellites may be neglected in a discussion of the changes of obliquity of a planet due to tidal friction; the prevailing term, save only for a short interval, is that due to the action of the Sun on its own tides. If this be so, then on examining the present state of affairs in the solar system we are faced by difficulties which had been previously settled by the action of the satellites. The present small obliquity of *Jupiter*, requiring an almost impossibly great viscosity if explained by solar tidal friction alone, had been regarded as a natural consequence of the tidal action of the satellites. And the large angle through which *Saturn* had tilted since the evolution of *Phœbe* had been looked upon as in great part due to the tidal action of its satellites.

The following considerations may perhaps lead to a solution of these difficulties. It will have been noticed that in the previous discussion of the Saturnian system we omitted the effect of the rings on the planet's obliquity. Now the tidal theory of an annular satellite has been briefly sketched in "Precession" (p. 518), and it has been shown that the resultant couple on a planet is practically the same as is obtained from the cross action of a large number of satellites on each other's tides. While all the secular terms in the expression for the rate of change of the dimensions of the ring vanish a secular change is produced in the planet's obliquity by the tides set up by the ring. This we can express as follows: If a, s, r are suffixes referring to the ring, the Sun,

* Derived from "Orbits," (68) and (73).

† An exception to this is the Moon; and the true significance of the exceptional nature of the Earth-Moon system pointed out in "Evolution" seems to be that in its case finite changes of obliquity and mean distance accompany one another; the one does not proceed very much more rapidly than the other.

and any satellite of the planet respectively, then the new terms in $2gn\frac{di}{dt}$ to be added to (7) are

$$\left\{-\tfrac{1}{2}\tau_a^2\sin\tfrac{1}{2}(i-j_a)-\sum_{r=1}^{r=m}\tau_a\tau_r\left(\sin\tfrac{1}{2}(i-j_a)+\sin\tfrac{1}{2}(i-j_r)\right)\right.$$
$$\left.-\tfrac{1}{4}\tau_a\tau_s\sin 2i\right\}\sin 2g. \quad (10)$$

In the case of *Saturn's* rings, if we accept Struve's figures for $i-j_a$, namely, $0'\cdot 74$, and Tisserand's avowedly doubtful estimate of their mass as $\frac{1}{1000}$ mass of *Saturn*, we obtain the following approximate value for $\frac{\tau_a}{\tau_s}$:

$$\frac{\tau_a}{\tau_s}=62700.$$

With this value we obtain from (10) the following terms to be added to the expression for $\frac{2gn}{\tau_s^2}\frac{di}{dt}$ for *Saturn* given in (9):

$$-(21600+346000+36300)\sin 2g \text{ or } -404000\sin 2g.$$

This is, of course, only a very rough approximation, but it is sufficient to show that the terms due to the ring, while of the same sign as those due to the cross action of the satellites, far outweigh them in magnitude. At the same time they are not apparently affected with that transitory nature which renders the satellites' tides ineffective in producing large permanent changes of obliquity in the planet. With the above figures representing the magnitude of the tides set up by the ring the difficulty referred to above disappears for *Saturn*; the further difficulty of the small obliquity of *Jupiter* also ceases to have any force if we assume that *Jupiter's* satellites have in the course of their evolution passed through an annular stage.

We may say, then, that the theory of planetary inversion suggests, but does not absolutely require as a condition for its truth, an annular stage in the history of the satellites of *Jupiter* and *Saturn*. More than this we do not care to state till a more detailed application of the tidal theory has been made to the case of a planet attended by a group of satellites. The very doubtful question whether perturbations in a ring of satellites could ultimately lead to the formation of one or several satellites must also be discussed before the difficulties considered in this section can be removed.

V. *Final Conclusions and Summary of Results.*

The previous part concluded with a mention of one or two difficulties which, unlike the more abstract difficulties connected with time and heterogeneity, may yield to analytical treatment.

on further investigation. Some explanation may be required for the appearance of this paper is so incomplete a form as is thus implied, and I may perhaps plead in excuse the desire not to overburden this already long paper with a discussion of the details rather than of the principles involved in the theory of planetary inversion. A further reason for not delaying the publication of this paper any longer may be found in the discussion on this subject between Professor W. H. Pickering and Professor F. R. Moulton, which has been going on in the columns of the *Astrophysical Journal.** And I should like to say a few words about their remarks on the subject.

Stimulated though one may be by Professor Pickering's persevering and successful search for a new satellite of *Saturn*, by his bold and equally successful idea of a retrograde orbit for it; and by his suggested explanation for it, one must be careful not to be misled by the vague terms in which he described his theory. These left ample room for the misunderstanding of the theory which, I believe, has invalidated Professor Moulton's criticism of it. The latter's original misconception led him to some further assumptions, which the above analysis of the theory has shown to be unnecessary, but which fundamentally affect the validity of his criticism.

In conclusion I will sum up briefly the view to which the present application of Sir George Darwin's tidal theory has led me. And first let me give a short summary of the results obtained in the investigation. In Part II. by an extension of the results previously obtained by Sir George Darwin I showed that for a planet moving round the Sun unattended by any satellite the stable position was with an obliquity between 0° and 90°, near 90° for all but large viscosities, and steadily decreasing in value as the viscosity increased. Any planet starting with an obliquity greater than 90° would, under the influence of solar tidal friction, tilt over until its obliquity had decreased below that value; this would hold good so long as no satellites with large tidal influence compared with the Sun were evolved.

In Part III. I proved that, if a satellite were present of the type that we find in the solar system, tidal friction would have no sensible effect on the position of its orbit. I further obtained the additional terms, due to the second satellite, in the expression for the secular changes in the planet's obliquity. In Part IV. I extended these results so as to admit of several satellites being present, and obtained a formula leading to the following conclusions: The direct terms arising from the action of a satellite on its own tides tend to drive the planet's axis of rotation into the ecliptic. The cross terms arising from the action of the satellites on each other's tides and on the solar tides tend to drive the axis of rotation out of the ecliptic into a

* 1905 December.

position making an angle of 90° with it; these are the predominant terms in most of the planetary sub-systems at present, and thus in the presence of a group of satellites of large tidal influence the stable value for the obliquity will be 180° or 0°, and the planet will move away from an unstable equilibrium position with an obliquity of nearly 90°. One exceptional case exists: if one of the satellites has a tidal influence far in excess of that of any of the others, and if this satellite is not too close to the planet, so that its proper plane does not make too small an angle with the planet's equatorial plane, then the prevailing term may be the one arising from the direct action of this satellite on its own tides, and the equilibrium position will be with the planet's axis of rotation nearly in the ecliptic, or with an obliquity just less than 90°.

In the same part I discussed the application of this theory, if true, to the past and present history of the solar system, and I came to the following conclusion: *Mercury*, *Venus*, and *Mars* have tilted over under the influence of solar tidal friction in accordance with the theory of Part II. Either under the influence of bodily tides of great viscosity they have gained an equilibrium position of small obliquity, or under the influence of ocean tides of small viscosity they are returning to a position of equilibrium with an obliquity of nearly 90°. Observation does not settle which of these two alternatives represents the case of *Mercury* and *Venus*, though for *Mercury* I incline to the former. It seems probable that the latter alternative is required to explain the obliquity of *Mars*. The case of the Earth I have omitted, as already fully dealt with by Sir George Darwin; but it is possible to fit into this theory the initial requirements of his discussion of the evolution of the Earth-Moon system. *Jupiter* must have evolved its satellites after its obliquity had decreased below 90°; partly under their influence it has been driven down towards a stable position of small obliquity, which it has now nearly reached. *Saturn* shed *Phœbe*, and possibly also *Iapetus* and *Hyperion*, while its obliquity was greater than 90°; as under solar tidal influence it passed through the critical position, where its obliquity was 90°, *Phœbe* sank down into the ecliptic in a retrograde orbit, while *Iapetus* and *Hyperion* moved over with the planet's equator. Afterwards the inner satellites were evolved, and under their influence and the influence of the rings *Saturn's* obliquity has steadily diminished—and is still diminishing—towards a small stable value. As seems highly probable for a planet further removed from the Sun, and therefore less likely to have its increasing rotation checked by solar tidal friction, the satellites of *Uranus* were evolved in an earlier stage of its evolution, before its obliquity had decreased to 90°; they have stopped the decrease in obliquity, which would arise from the solar action, and they are now driving *Uranus* back to a stable position with an obliquity of 180°. *Neptune*, with its one satellite of extremely large tidal influence, is being driven towards an equilibrium

position with an obliquity of 180°. I should add that uncertainty as to the data for the satellites of *Uranus* and *Neptune* leaves even the present direction of motion of their equators very doubtful, but that the results above given seem on the whole the most probable.

In the concluding section of this part I gave reason to believe that the effect of the satellite's tides on the obliquity of the planet might only be transient. It seems very possible, from such investigation as I have made into the tidal theory of a system of satellites, that their orbits would be enlarged by tidal friction very rapidly compared with the rate at which the planet would tilt over; thus they would not remain tidally efficient long enough to perceptibly affect the obliquity of the planet. If this should be the case—and it seems probable—then I suggest as the easiest explanation of certain remaining difficulties that the satellites of *Jupiter* and *Saturn* have passed through an annular form at some previous stage in their history. This latter idea is not essential to the successful working out of the theory; at present it is only put forward very tentatively indeed, and as a subject for further research.

Viewed broadly, then, the theory of planetary inversion, though it entails some difficulties of detail, remains a tenable hypothesis. As explained by Sir George Darwin's tidal theory it involves three main assumptions: (1) that the outer satellites of a planet were evolved before the inner ones; (2) that the determining factor producing secular alterations in a planet's obliquity has been tidal friction; and (3) that the time involved in the scheme is not so great as to invalidate the ordinary dynamical equations. A justification for these assumptions may perhaps lie in the satisfactory explanation which the theory affords both of the large obliquities of *Uranus* and *Neptune* and of the presence of a satellite such as *Phœbe*. The secular motions with which the theory is concerned are so extremely slow that it can hardly yet be proved or disproved by reference to the gravitational theory of the motions of planets and their satellites;* the theory would gain some support by the discovery of satellites to *Uranus* and *Neptune* of the same type as *Phœbe*, if their motion were retrograde; it would be overthrown if their motion were direct. The theory remains then at present a speculative hypothesis, which is on the whole well supported by the theory of tidal friction, and which gives the only explanation so far offered for certain facts.

My indebtedness to Sir George Darwin's previous work on the tides has been apparent throughout this paper, but I wish to take this opportunity of thanking him most heartily for the helpful advice and kind encouragement which he has given me whilst writing it.

* This was written before I had seen the paper in which Mr. Cowell successfully explained the apparent secular acceleration of the Sun and Moon by an application of the theory of tidal friction.

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Gonville and Caius College, Cambridge:
1906 *April.*

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXVI. MAY 11, 1906. No. 7

W. H. MAW, Esq., PRESIDENT, in the Chair.

Edmund Dickson, F.G.S., 2 Starkie Street, Preston, Lancashire;
Jacob Halm, Ph.D., Royal Observatory, Blackford Hill, Edinburgh;
John William Hicks, Ordnance Committee Office, Woolwich;
William Malin Hunt, 48–50, London Road, Nottingham; and
Edwin Baikie Simpson-Baikie, Lieut. R.N.R., 142A The Bluff, Yokohama, Japan,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Arthur Grant Stillhamer, Yerkes Observatory, Williams Bay, Wisconsin, U.S.A. (proposed by S. W. Burnham);
Ralph Falcon, M.A. Oxon., Barrister-at-Law, Camerton Hall, Workington, Cumberland (proposed by Cecil G. Dolmage).

Sixty-six presents were announced as having been received since the last meeting, including, amongst others :—

Publications of the Astronomical Laboratory, Groningen, Nos. 15, 16 (De Sitter, Photographic Parallax Tables, and

Kapteyn, Trigonometrical Formulæ), presented by the Laboratory; G. W. Hill, Collected Mathematical Works, vol. iii., presented by the Author; Oxford University Observatory, Miscellaneous Papers, vol. ii., presented by the Savilian Professor of Astronomy; Radcliffe Catalogue of Stars for 1900 (A. A. Rambaut), presented by the Radcliffe Trustees; Eighteen Charts of the Astrographic Chart of the Heavens, presented by the Royal Observatory, Greenwich; and Ten Charts presented by the San Fernando Observatory.

On the Ancient Eclipses of the Sun. By E. Nevill.

It was with much interest that I read Mr. Cowell's recent papers on the ancient eclipses of the Sun and the values they indicate for the secular accelerations of the longitudes of the Sun, Moon, and lunar node, and it is with some curiosity that I have waited for the last six months to see if any of the distinguished astronomers conversant with the subject would critically examine the results which Mr. Cowell has deduced.

In the first of these papers (*Monthly Notices*, vol. lxv. p. 861) Mr. Cowell reaches the conclusion that if the Moon's secular acceleration be taken as $+7''\cdot0$, in order to represent the ancient eclipses of the Sun it is necessary to reduce to about $+4''\cdot4$ the secular acceleration of the Moon's angular distance from its node, corresponding to a reduction of the secular acceleration of the Moon's node to only a third of its theoretical value.

In the second of these papers (*Monthly Notices*, vol. lxvi. p. 3) Mr. Cowell points out that, as this reduction of the Moon's nodical secular acceleration is inconsistent with the theory of gravitation, the requisite value of the secular acceleration of the Moon's angular distance from its node should be obtained by adopting the theoretical value of the secular acceleration of the node and increasing the secular acceleration of the Moon's mean longitude from $+6''\cdot8$ to $+10''\cdot9$, and ascribing a secular acceleration of $+4''\cdot1$ to the mean longitude of the Earth, so as to leave unchanged the epoch of conjunction of the Sun and Moon in mean longitude.

The results deduced in these two papers are quite distinct, and form two questions which may well be examined separately.

The first is the existence of an apparent secular acceleration of $+4''\cdot4$ in the angular distance of the Moon from its node.

The records of the ancient eclipses of the Sun and the values they indicate for the secular accelerations of the Moon's mean longitude, longitude of node, and longitude of perigee have been examined in some detail in one of the sections of my unpublished memoir on the errors of the lunar tables, and from it can be derived further information on the subject considered in Mr. Cowell's papers.

The eclipses are referred to Hansen's *Tables du Soleil* and to Hansen's *Tables de la Lune* under the following forms:—

A. Hansen's Tables, with his final values for the secular accelerations and motion of the node.

B. Hansen's Tables, after replacing his tabular values of the secular accelerations by those derived theoretically from the secular diminution of the eccentricity of the terrestrial orbit and making the small consequent corrections necessary to bring the amended tables into accord with the modern observations.

C. Hansen's Tables, after applying the corrections indicated by a complete discussion of the lunar observations between the years 1650 and 1900, employing for the secular acceleration of the mean longitude the value $+7''\cdot43$, of the longitude of the node the value $+6''\cdot07$, and of the longitude of the perigee the value $-32''\cdot53$.

The only eclipses considered are those at least two thousand years prior to the present epoch, as those of later date are of little real value for the desired purpose.

In the following $\Delta\phi$ represents the distance of the central line of totality from the assumed place of observation, measured on the meridian in degrees of latitude, a positive sign showing that the central line of totality is to the south of the assumed place of observation.

I. *The Eclipse of Agathocles.*—Recorded as having happened on -309 August 14, on the second day after Agathocles had left Syracuse on his way by sea towards Carthage. It being unknown whether he sailed south or north of Sicily, it is uncertain whether the eclipse was observed from $36\frac{1}{2}°$ or from 38° N. latitude, in both cases the longitude being about 15° E. The different modifications of the lunar tables yield the following values of $\Delta\phi$ measured from the latitude of Syracuse (37° N.), and to them has been now added the value that has been obtained from Mr. Cowell's data by an approximate calculation:

$$A = +1°\cdot8 \qquad B = +0°\cdot8 \qquad C = +0°\cdot8 \qquad \text{Cowell} = -0°\cdot9$$

As the width of the zone of totality exceeds two degrees, it is apparent that the eclipse is represented by all four systems of data.

II. *The Eclipse of Pelopidas.*—A very large, but not necessarily total, eclipse of the Sun, said by Plutarch to have occurred before Pelopidas left Thebes on the expedition against Alexander of Pheræ. Apparently it must have been the eclipse of -363 July 13. The values of $\Delta\phi$ are

$$A = -10°\cdot8 \qquad B = -11°\cdot8 \qquad C = -11°\cdot5 \qquad \text{Cowell} = -16°\cdot0$$

These all indicate a large eclipse, but the results are of little use.

III. *The Eclipse of Ennius.*—Stated by Cicero to have occurred at Rome in -399 June 21 toward sunset. It appears doubtful if the Sun was totally eclipsed before sunset, or even if

it were total at all. If there had been any certainty on this point it would have been a most valuable criterion, and deserved the great weight assigned it by Hansen. The values of $\Delta\phi$ are

$$A = -1^\circ{\cdot}2 \qquad B = +10^\circ{\cdot}4 \qquad C = +7^\circ{\cdot}4 \qquad \text{Cowell} = +3^\circ{\cdot}1$$

According to Hansen's values the Sun set after totality; but according to the modified forms it must have set some time before totality, and the eclipse cannot have been total near Rome.

IV. *The Eclipse of Lysander.*—Stated by Xenophon to have occurred in the autumn of the year that Lysander took Athens, which would correspond to the eclipse of -403 September 3. It must have been a large eclipse, but not necessarily a total eclipse in Greece. The values of $\Delta\phi$ are

$$A = -0^\circ{\cdot}2 \qquad B = +2^\circ{\cdot}6 \qquad C = +1^\circ{\cdot}6 \qquad \text{Cowell} = -2^\circ{\cdot}4$$

The eclipse was annular, and according to all four sets of data must have been very large at Athens.

V. *The Eclipse of Thucydides.*—Stated by Thucydides to have occurred in the summer of the first year of the Peloponnesian War, and to have been nearly, but not quite, total at some spot in Greece—probably Athens, but quite possibly some place in the northern Ægean Sea, or even in the Ionian. It is this uncertainty which weakens the value of this eclipse as a test. The eclipse was only annular, and occurred so soon before sunset that stars might have been seen as recorded, even had the eclipse been only a large eclipse. The values of $\Delta\phi$ are

$$A = -17^\circ{\cdot}8 \qquad B = -1^\circ{\cdot}8 \qquad C = -5^\circ{\cdot}8 \qquad \text{Cowell} = +0^\circ{\cdot}1$$

Hansen's values fail to account for this eclipse; both the theoretical secular accelerations and Mr. Cowell's data represent it as seen at Athens, and the data C as if seen from the northern Ægean.

VI. *The Eclipse of Thales.*—Stated by Herodotus to have occurred during a battle, fought probably at some place in Asia Minor, between the Lydians under Alyattes and the Medes under Cyaxares, at the end of a war of some length, during the period when Labynetus was king of Babylon. This war must have happened after the destruction of the Assyrian Empire by the Medes and Babylonians, and so have been later than the year -600. According to both Herodotus and Pliny, it was the eclipse predicted to the Ionians by Thales, and the date assigned by Pliny corresponds with that of -584 May 28.

There exist no means of ascertaining the position of the battlefield, and all that can be assured is that in all probability it was some spot on the great road from the Cilician Gates, through Iconium, to Sardis; though there is always the possibility that it was on the northern road by which Cyrus subsequently invaded Lydia, which passed by Pteria, in Northern Cappadocia.

Airy, Hind, and Hansen identify this eclipse with that of −584 May 28, which, according to Hansen's Tables, crossed Southern Asia Minor; and it is difficult to reconcile the existing accounts with any other eclipse. It is true that recent investigation has shown that the data assumed in Hansen's Tables require such modification that the zone of totality of the eclipse of −609 September 28 may have passed over the north of Asia Minor, crossing the northern route afterwards followed by Cyrus; but as this eclipse happened before the fall of the Assyrian Empire it must have occurred prior to the war between the Medes and Lydians. Similar permissible changes in the data of Hansen's Tables show that the zone of totality of the eclipse of −556 May 17 may also have crossed the southern portion of Asia Minor, traversing the southern route from the Cilician Gates to Sardis, upon which the battle was fought in all probability; but if this eclipse be assumed, Crœsus could not have succeeded Alyattes until after −556, and it is difficult to compress the events of his reign into the ten years between that date and the capture of Sardis by Cyrus in about −545. Yet it is difficult to reconcile the earlier date of the eclipse with the statement of Herodotus that Labynetus was king of Babylon both at the epoch of the eclipse and at the capture of Sardis by Cyrus, as Nabu-kudur-uzur (Nabuchadrezzar II.), who reigned in Babylon in −584, died in −561; but if the later eclipse were adopted, then the king of Babylon at both events may have been Nabu-nahid (Nabonidus), who reigned from −556 to −537.

The values of $\Delta\phi$ for the eclipse of −584 May 28, measuring from Iconium, are

$$A = -2^{\circ}\cdot 0 \qquad B = +3^{\circ}\cdot 1 \qquad C = +1^{\circ}\cdot 1 \qquad \text{Cowell} = -3^{\circ}\cdot 0$$

and as the zone of totality considerably exceeded two degrees in width, all four sets of data will serve to bring the phase of totality within permissible limits of latitude. But according to the different data, totality is reached at sunset at east longitudes:

$$A = 44^{\circ} \qquad B = 23^{\circ} \qquad C = 29^{\circ} \qquad \text{Cowell} = 29^{\circ}$$

and as the probable longitude of the battlefield lies between 30° and 32°, except in the case of Hansen's data, the Sun must have set before the eclipse was total, though in all cases it would have been very largely eclipsed before reaching the western horizon.

Would this suffice to meet the exigencies of the account given by Herodotus?

The values of $\Delta\phi$ for the eclipse of −556 May 19 are

$$A = -5^{\circ}\cdot 0 \qquad B = +2^{\circ}\cdot 7 \qquad C = +1^{\circ}\cdot 0 \qquad \text{Cowell} = +5^{\circ}\cdot 0$$

and the zone of totality is narrow, little exceeding half a degree. The Sun in all cases would at totality be well above the western

horizon; and according to data C, and possibly B, it would cross the probable position of the field of battle. Apart from chronological difficulties, this eclipse seems to agree with the account given by Herodotus even better than the earlier one. To throw over the circumstantial account given by Herodotus on the ground that he was credulous and related fables does not seem sound; and it must be remembered that recent discoveries have generally confirmed the accuracy of Herodotus, even when his accounts seemed most improbable to earlier critics.

VII. *The Eclipse of Larissa.*—According to Xenophon this eclipse occurred at the capture of the "Median" city of Larissa by the "Persians"; and, from the account of its effects, it must have been a total eclipse to have spread such consternation amongst the defenders of the city that they fled from the walls. The ruins of Larissa seen by Xenophon have been identified with certainty with the mounds of Nimrud, covering the remains of the Assyrian city of Calah. As the Sun represented Asshur, the ruling deity of Assyria, its eclipse would account for the terror of the defenders of Calah, who would take the darkness overspreading the Sun as indicating that the gods had decreed the ruin of Assyria.

With the imperfect knowledge of Assyrian chronology then alone available to guide him, Airy was led, in 1856, to identify this eclipse with that of −556 May 19, and showed that, according to Hansen's Tables, the narrow zone of totality passed nearly centrally over Larissa, and that there was no other eclipse within a period of forty years which could have been total at Larissa. But this eclipse cannot be reconciled with the theoretical value of the secular acceleration of the Moon's longitude, and it has proved the great obstacle to any reduction of Hansen's tabular values of the accelerations to the smaller values indicated by modern observations, as well as by theory, because any such reduction must throw the zone of totality of this eclipse many hundreds of miles to the south of Larissa.

Professor Newcomb and others seem disposed to evade the difficulty by either ignoring the eclipse, throwing over the tradition as unfounded, or ascribing the cause to some extraordinary meteorological phenomenon, and not to an eclipse of the Sun. I do not think this can be justified, and can see no reason for disbelieving the traditional account, which is so much in harmony with what is known of the Assyrian character; all the more so as the whole course of recent discovery has tended to confirm the accuracy of these traditional records of the events of ancient history.

As the eclipse of −556 May 19 cannot be reconciled with the value of the secular acceleration indicated both by theory and by the modern observations of the Moon, it is certain that it cannot be the eclipse which occurred at the capture of Larissa.

Since the epoch of Airy's identification of this eclipse much progress has been made in our knowledge of Assyrian history

and chronology, and the actual dates of the greater part of the known history of Assyria have been determined with certainty; but, often as this eclipse has been discussed since Airy's memoir of 1857, it does not seem to have been noticed that the capture of Larissa, the Assyrian city of Calah, by either Medes or Persians cannot possibly have taken place in −556. Nineveh, Calah, and the other great cities of Assyria disappear from history before −600, and no reference to the existence of these great cities is known to occur at any subsequent period, either in Babylonian, Persian, Egyptian, or Grecian records. They were all destroyed together during the great invasion prior to −600, and the very state of the ruins at the present time shows that the destruction was sudden and once for all. Every inhabitant perished or was transported in slavery to some distant spot, and the cities were never allowed to be re-inhabited. The capture of Larissa to which the tradition refers must be the capture of the Assyrian Calah by the Medes and Babylonians prior to −600, and could not refer to the capture by the Persians of a town built by the Medes on the site of the older Assyrian city of Calah, a town of whose existence there is no record, and of whose remains there is no sign amongst the existing ruins of Calah. As before remarked, the very state of the ruins shows that Calah was an Assyrian city when destroyed prior to −600, and that its destruction was final.*

The great siege of Nineveh began in −608, and after a long siege ended with the destruction of the city in −605. Were the surrounding cities of Calah, Dur-Sargina, &c., besieged and captured before or after the capital, Nineveh? The whole tenor of ancient history shows that they would be besieged and taken one after the other, and not all at once. If Calah was besieged and taken before Nineveh, then the eclipse must have been that of −609 September 30. If besieged and captured after Nineveh had fallen, then the eclipse must have been that of −602 May 18.†

* Even if it had been permissible to suppose that the Medes, after capturing and destroying the city of Calah, had refounded a Median town on the site, though a supposition inconsistent both with history and with the state of the ruins, and that it was the capture by the Persians of this hypothetical new town of the Medes, to which the tradition referred, still even this would not save the eclipse of −556 May 19. For just as it is certain that the capture of the Assyrian city of Calah by the Medes and Babylonians occurred nearly half a century before this eclipse of −556 May 19, so is it equally certain that Cyrus, King of Ansan and Persia did not revolt against the Medes until the sixth year of Nabu-nahid (Nabonidus), King of Babylon, which corresponds with −548, eight years after the eclipse, and did not attack this region until the invasion of Babylonia in −538.

† It is known that the great palace of Calah was burnt down from some cause and rebuilt by Assur-bani-pal's successor, Assur-etil-ilani, some time between −620 and −615. It has been assumed that this burning took place during the Scythian (or Mandaian) invasion, which occurred about the time of Assur-bani-pal's death in −625. This assumed capture of Calah, and of Calah only, out of all the surrounding cities by the Scythians about −625 does not

The values of $\Delta\phi$ for these two eclipses are :

−602 May 18	A = $+12^{\circ}\cdot0$	B = $+0^{\circ}\cdot2$	C = $+2^{\circ}\cdot0$	Cowell = $-0^{\circ}\cdot6$
−609 Sept. 30	= $-9\cdot7$	= $-1\cdot2$	= $-3\cdot4$	= $-8\cdot9$

The zone of totality of these eclipses was wide in each case, and both occurred near midday. Neither eclipse can have been total at Calah, according to Hansen's data ; but the eclipse of −602 May 18 was total on all three other systems of data, and the eclipse of −609 September 30 was total according to the theoretical values of the secular acceleration. This great obstacle to the adoption of the theoretical value of the secular accelerations vanishes.

VIII. *The Eclipse of Archilochus.*—Described by Archilochus in one of his poems, and from the description must have occurred at midday, and been at least annular, but probably total, where it was seen. Beyond this everything is vague. It may have been any eclipse of this nature between −710 and −640 ; and, though probably observed at Thasos, may have been seen from Paros, or even from some other place on the Ægean Sea. The eclipses during this period which it might have been are those occurring on

−710	March	14	Total
−703	October	19	Annular
−688	January	11	Annular
−656	April	15	Total
−650	June	7	Annular
−647	April	6	Total
−640	November	11	Annular.

Mr. Cowell, like Professor Millosevich, selects the eclipse of −647 April 6 because it agrees with the data he adopts ; but this is considerably later than the date usually assigned to this

harmonise with the rest of the events of this period, nor even with probability. The very fact that an attempt was made to rebuild the palace, though in an inferior style, by Assur-bani-pal's successor, Assur-etil-ilani, would strongly indicate that the palace was destroyed by an accidental fire, similar to that which happened nearly three centuries before. If the city had been captured and burnt with the palace at this earlier epoch, it is not likely that an attempt would have been made to re-erect an inferior building amongst the ruins of a destroyed city when the king had so many other magnificent palaces in the surrounding cities. But if the palace of the second city of Assyria had been accidentally burnt, leaving the great city in existence, then it is probable enough that an attempt should have been made to restore the palace accidentally destroyed, though even in an inferior style, rather than leave the ancient capital of Assyria without any residence for the king. Certainly no attempt was made to restore any of the other palaces when once they had been destroyed with the surrounding cities during the conquest by the Medes and Babylonians.

poet. Still, as pointed out by Mr. Lynn, Archilochus has referred to the capture of Magnesia by the Cimmerians, which took place during the reign of Assur-bani-pal of Assyria, and so must be later than −668, but probably before −660, the beginning of the trouble with Elam. The values of $\Delta\phi$ for these eclipses, supposed seen from Thasos, are :

−710 March 14	A = + 8°·1	B = −10°·7	C = − 8°·6	Cowell =	...
−703 Oct. 19	− 7·3	+ 2·7	− 0·7		
−688 Jan. 11	+ 13·5	+ 6·3	+ 7·9		−1·8
−656 April 15	+ 16·1	− 2·0	+ 0·7		
−650 June 7	− 8·8	− 8·2	− 8·2		
−647 April 6	+ 0·3	− 12·9	− 9·6		+ 0·5
−640 Nov. 11	− 25·4	− 7·0	− 12·5		

From this it appears that the eclipse of Archilochus may be represented on the data A by assuming it to be the eclipse of −647 April 6, as seen from Thasos ; on the data B, employing the theoretical accelerations, by assuming it to be the eclipse of −656 April 15 as seen from Thasos or the eclipse of −703 October 19 as seen from Paros ; on the data C by assuming it to have been either the eclipse of −703 October 19 or that of −656 April 15, as seen from Thasos ; or by Mr. Cowell's data by supposing, as he does, that it was the eclipse of −647 April 6, as seen from Thasos, or the eclipse of −688 January 11.

It is apparent that this eclipse can afford no information as to the true values of the secular accelerations, as none of these seven eclipses, seen from either Thasos or Paros, can be found which will harmonise with any permissible values.

IX. *The Eclipse of Susa.*—Recorded in a tablet of the reign of Assur-bani-pal, immediately before his expedition against Elam in −659 : "Te-umman devised evil, and Sin devised against him forebodings of evil. In Tammuz an eclipse at evening. He troubled the lord of light, and the setting Sun thus also for three days was troubled. It went forth for the end of the reign of Elam." An eclipse of the Sun could not trouble the Sun for three days, but Dr. Pinches considers that the eclipse and the troubling of the Sun should be regarded as distinct occurrences. Even were there objections to so differencing them, the record may be interpreted as reading that the Sun was so troubled or eclipsed "*on*" three days, or that there had been three eclipses, probably at sunset.

The inscription does not say that the eclipse was total ; a large eclipse at sunset would suffice ; but the month, Tammuz, of the specified eclipse is only consistent with the eclipse of −660 June 27. The values of $\Delta\phi$ are :

A = + 1°·6 B = + 13°·5 C = + 7°·9 Cowell = + 6°·0

All occurred near sunset. According to Hansen's data it would have been annular before sunset ; but, according to the data C

and those adopted by Mr. Cowell, only a large partial eclipse at sunset, whilst the system depending on the purely theoretical data would make it a much smaller eclipse. There are two other eclipses at this time; one, that of −661 January 12, would have been a large eclipse at sunset; and another, in −663, would also have been visible, but not at sunset.

X. *The Eclipse of Esar-haddon.*—Recorded in the form, "Since my lord went to Egypt an eclipse has taken place in the month of Tammuz" (June), on an Assyrian tablet of the reign of Esar-haddon, between −680 and −668. The only large eclipse which can answer to this description is that which occurred on −678 June 17. There is absolutely no other in the reign of this king which it could have been. Yet this eclipse occurred several years before Esar-haddon's great Egyptian wars; and, if it be the eclipse of this date, the statement that it occurred when the king had gone to Egypt must refer to one of the early expeditions to the frontiers of the empire, which are only imperfectly recorded in the early annals of this king of Assyria.

The values of $\Delta\phi$ are:

$A = +19^\circ\cdot6$ $B = +5^\circ\cdot6$ $C = +11^\circ\cdot3$ $\text{Cowell} = +4^\circ\cdot8$

It will be seen that this eclipse would have been a very large eclipse at Nineveh according to the data employed by Mr. Cowell, or those depending on the theoretical secular accelerations.

XI. *The Eclipse of Nineveh.*—Recorded under the form "Eponomy of Bur-Sagall, Governor of Gozan. A revolt in Assur took place in the month Sivan, and the Sun was eclipsed" on an Assyrian cuneiform tablet as occurring in the eighth year of Assur-dan III., corresponding to −762. Hence the eclipse must have been that of −762 June 15. It will be seen that the eclipse is not stated to have been total, nor is anything recorded indicating that it was total; and though undoubtedly it must have been large, it must not be assumed to be necessarily a total eclipse, as assumed by Mr. Cowell. In consequence it is not of great value for ascertaining the probable amount of the secular accelerations, though highly important as fixing Assyrian chronology. The values of $\Delta\phi$ are:

$A = -4^\circ\cdot1$ $B = -6^\circ\cdot7$ $C = -5^\circ\cdot9$ $\text{Cowell} = -0^\circ\cdot8$

As the zone of totality was fairly wide, Mr. Cowell's data make it total at Nineveh, but on the other systems it is only very large. Either would satisfy the record.

These eclipses are considered in my memoir, and to them may be added the new eclipse recorded in the Babylonian tablet deciphered by Mr. King and quoted in part by Mr. Cowell.

XII. *The Eclipse of Babylon.*—Recorded as occurring on the "26th day of the month Sivan in the 7th year." From the other details the eclipse was most likely a total eclipse with a vivid

corona. Assuming that the eclipse occurred in the first half of the eleventh century it would seem certain that this eclipse must have been that of −1069 June 19, which occurred in the month Sivan of the seventh year of E-Ulmas-sakin-sumi, King of Babylon, thus being in strict accord with the record. But as this eclipse could not possibly have been total at Babylon according to his adopted data, Mr. Cowell is led to substitute the eclipse of −1062 July 30. The discrepancy of seven years in the epoch of the king's reign might not be deemed fatal to this identification, owing to the uncertainty in these very early epochs; but can July 30 ever have been in the month Sivan, which corresponds with May or June? Could it even have corresponded with Tammuz, the next month, or must it not be held to be some day of the month after? As the inscription must be regarded as an actual record, the month cannot have been in error, and the record cannot be changed by reading Tammuz, or even some later month, for the Sivan actually recorded.

This eclipse of −1069 June 19 is the only one which occurred during the month Sivan which could have been visible as a total eclipse from Babylon during the first half of the eleventh century. There are annular eclipses in this month during this period, but they could not have been even large eclipses near Babylon, and there are other eclipses which might have been total near Babylon, but could never have been described as occurring in the month Sivan.

If it were permissible to assume an earlier epoch, then the record might refer to one of the kings of the Isin dynasty, and correspond with either the eclipse of −1116 June 28 or −1123 May 18, both of which may have been total at Babylon.

The values of $\Delta\phi$ for the preceding eclipses are:

−1062 July 30	$A = -\ 2^\circ{\cdot}2$	$B = -\ 7^\circ{\cdot}0$	$C = -\ 5^\circ{\cdot}6$	$\text{Cowell} = +\ 0^\circ{\cdot}8$
−1069 June 19	$= +30{\cdot}7$	$= +13{\cdot}0$	$= +16{\cdot}5$	$= +12{\cdot}3$
−1116 June 28	$= +10{\cdot}8$	$= -\ 6{\cdot}9$	$= -\ 0{\cdot}3$	$= +\ 4{\cdot}0$
−1123 May 18	$= +11{\cdot}7$	$= +\ 1{\cdot}2$	$= +\ 3{\cdot}2$	$= -\ 2{\cdot}1$

It will be seen that the line of totality of the eclipse of −1069 June 19 cannot be brought over Babylon by any of the four systems of data or by any system within the limits of possibility. Hence, though otherwise in complete accordance with the recorded account, it cannot have been the recorded eclipse. The eclipse of −1062 July 20 can be made total at Babylon either by Mr. Cowell's data or by a slight modification of the very different data obtained by Hansen, and therefore by any number of intermediate combinations lying between the two systems. If it be adopted as the eclipse corresponding to that recorded in the cuneiform tablet, it must be held as of little use for indicating the true value of the secular acceleration; but the discordance between the month of the eclipse and that stated in the inscription must be held to render such an identification very doubtful.

Mr. Cowell does not give any reasons for assigning this eclipse to a period subsequent to −1100, nor does he state whether Mr. King furnished such reasons, nor even whether the rest of the inscription (by stating the king's name or dynasty) affords means for fixing such a limit. Unless such reasons exist for dating the record after −1100, the eclipse would seem more likely to have been that of −1116 June 28, or −1123 May 18, than that of −1062 July 30, since the eclipse of −1069 June 19 is out of the question, as not even large near Babylon. If the inscription permits of the recorded eclipse being identified with one of these earlier eclipses it would be most valuable for fixing the true value of the secular acceleration and motion of the lunar node, as it would clearly distinguish between the four representative sets of data.

The preceding comparisons show that the eclipses, which by slight permissible alterations in the assumed data may be represented by the four very different sets of assumed values for the secular accelerations and motions of the Moon's node, are as follows:—

Name.	Obs. Phenomenon.	A		B		C		Cowell.	
		Date.	Δφ.	Date.	Δφ.	Date.	Δφ.	Date.	Δφ.
I. Eclipse of Agathocles	Total	− 309	+ 1°·8	− 309	+ 0°·8	− 309	+ 0°·8	− 309	− 0°·9
III. Eclipse of Ennius ...	Large	− 399	− 1·2	...	...	...	...	− 399	+ 3·1
IV. Eclipse of Lysander	Large	− 403	− 0·2	− 403	+ 2·6	− 403	+ 1·6	− 403	− 2·4
V. Eclipse of Thucydides	Nearly total	...	...	− 430	− 1·8	− 430	− 2·8*	− 430	+ 0·1
VI. Eclipse of Thales ...	Total	− 584	− 2·0	...	...	− 556	+ 1·0	...	...
						− 584	+ 1·1	...	...
VII. Eclipse of Larissa ...	Total	− 556?	− 0·6	− 602	+ 0·2	− 602	+ 2·0	− 602	− 0·6
VIII. Eclipse of Archilochus	Total	− 647	+ 0·3	− 656	− 2·0	− 656	− 0·7	− 647	+ 0·5
				− 703	+ 2·7	− 703	+ 0·7	− 688	− 1·8
IX. Eclipse of Susa ...	Large	− 660	+ 1·6	...	...	− 660	+ 7·9	− 660	+ 6·0
X. Eclipse of Esarhaddon	Large	...	...	− 678	+ 5·6	...	...	− 678	+ 4·8
XI. Eclipse of Nineveh...	Large	− 762	− 4·1	− 762	− 6·7	− 762	− 5·9	− 762	− 0·8
XII. Eclipse of Babylon	Total	−1062	− 2·2	−1123	+ 1·2	−1116	− 0·3	−1062	+ 0·8
								−1123	− 2·1

Mr. Cowell considers that the fact that the system of secular mean motions and acceleration adopted by him renders total the five eclipses

−1062	July	30	at	Babylon
− 762	June	14	„	Nineveh
− 647	April	5	„	Thasos
− 430	August	3	„	Athens
+ 197	June	3	„	Utica

* Observed from the northern Ægean instead of Athens.

is so remarkable that it cannot be held a chance coincidence, but must be regarded as demonstrating the accuracy of the adopted system. It is necessary to remember, however, in considering this claim—

That the eclipse at Babylon is stated explicitly to have occurred in the month Sivan, whereas the eclipse adopted occurred in Tammuz or later;
that the eclipse at Nineveh is not recorded as being total, as assumed without authority by Mr. Cowell, and so may have been only a large eclipse;
that a total eclipse may be found to represent that at Thasos on any system of data, so that it is valueless as evidence of the accuracy of any system;
that the eclipse at Athens, though annular according to Mr. Cowell's data, is only recorded as having been very large, whilst it is represented just as well by other systems of data as by that adopted by him; and
that the eclipse of Utica has not been considered, as its epoch is so late that it cannot be regarded as of any value.

Taking these considerations into account it will be seen that the fact that these five eclipses selected by Mr. Cowell are rendered total by his data cannot be regarded as establishing the accuracy of the data adopted. Nor can it be urged that, though each of the preceding five eclipses may be represented just as well by other systems of data, yet Mr. Cowell's is the only system which will represent five eclipses, for the preceding examination shows that out of the twelve eclipses considered Hansen's theoretical values can be made to represent seven or possibly nine; that the strictly theoretical values of the secular accelerations will represent seven or eight; that the data derived exclusively from the modern observations will represent six at least, but possibly eight; and that Mr. Cowell's data with some slight amendment may be made to represent as many as ten eclipses. The mere fact that a system of data represents a certain number of rather vaguely defined eclipses cannot be regarded as establishing anything.

In truth, the results which have been given show that unless it can be established that an eclipse was to all intents total at a specified place within a narrow definite period of years, it can be of small use as a criterion of the true values of the mean motions and secular accelerations. Of those in the preceding list there is but one possessing these requirements, and that is the eclipse of Larissa, though possibly the eclipse of Babylon may prove to be another.

In my memoir, in addition to the series of eclipses which has been considered in the preceding, there was also taken into account a series of twelve eclipses of the Sun, observed during the Chow dynasty in China, and presumably observed from the

ancient capital of Heeng-Yang, in Shensee, where there still exists the remains of a very ancient observatory. It is possible, however, that in some cases the place of observation may have been the neighbouring city of Chang-gan, which was the residence of some of the emperors during this period. Some of these eclipses are expressly recorded as total; and all seem to have been very large eclipses, if not at least annular. In each case the exact date of the eclipse is definitely fixed by the record, so that there is no uncertainty in this respect.

The eclipses are :—

				A	B	C	Cowell.
XIII.	−497	Sept. 22	Annular $\Delta\phi =$	$-4^\circ.2$	$= +3^\circ.6$	$= +1^\circ.8$	$= -4^\circ.2$
XIV.	−526	April 18	Annular	+ 8·3	−3·6	+0·0	− 5·4
XV.	−545	Oct. 3	Total	− 6·0	+4·2	+2·9	+ 6·8
XVI.	−548	June 19	Total	+ 4·2	+3·4	+3·3	− 0·2
XVII.	−549	Jan. 5	Annular	+13·2	+1·5	+6·4	+11·7
XVIII.	−574	May 9	Total	− 1·1	−1·9	−1·4	+ 2·2
XIX.	−600	Sept. 20	Total	−20·1	−2·3	−5·1	+ 2·0
XX.	−625	Feb. 3	Annular	+ 6·9	−0·3	+2·4	+ 8·6
XXI.	−663	Aug. 28	Total	−14·8	−3·4	−5·4	−12·2
XXII.	−667	Nov. 10	Annular	−12·3	−0·9	−4·7	−11·7
XXIII.	−668	May 27	Annular	− 3·5	−7·3	−5·5	+ 0·3
XXIV.	−708	July 17	Total	−19·9	−4·2	−5·8	− 3·0

There are several other eclipses during this period recorded as having occurred, whose place of observation is too uncertain to render them of value.

Use was also made of four more recent eclipses, recorded in more indefinite language, only the year and season being stated, but all explicitly described as total. These are the eclipses :—

XXV.	−180	Mar. 4	Total $\Delta\phi =$	$+1^\circ.6$	$= -3^\circ.5$	$= -2^\circ.1$	$= +0^\circ.9$
XXVI.	−187	July 17	Total	−8·3	+ 1·1	− 1·0	+ 1·9
XXVII.	−299	July 26	Total	−2·9	− 6·9	− 5·9	− 3·3
XXVIII.	−381	July 13	Total	−6·0	−13·8	−11·2	−15·6

This last eclipse is discordant on all systems of data, and could only have been total in Mongolia.

It will be seen that out of these sixteen eclipses observed in China, by regarding those for which $\Delta\phi$ is less than $2\frac{1}{2}^\circ$ as total or annular, and those for which $\Delta\phi$ lies between $2\frac{1}{2}$ and 6° as so large and conspicuous as to be practically total, the number in the case of each of the four sets of data being considered is

	A	B	C	Cowell.
Total or annular	2	6	6	6
Very large	5	7	8	4
Discordant	5	1	1	4

Practically the last three systems all serve to represent these Chinese eclipses as well as could be anticipated, and show the caution that must be employed in drawing deductions from such a circumstance.

In concluding this examination it must be pointed out that the preceding considerations do not invalidate Mr. Cowell's conclusion that the Moon's argument of latitude F possesses a secular acceleration of about $+4''\cdot4$ per century; they show that the eclipses adduced by Mr. Cowell do not suffice to establish it as he supposed, and are quite consistent with systems of data very different from that adopted by him, and which do not involve the difficulties inseparable from his. But it must be distinctly understood that this is all. In many respects the preceding examination of the ancient eclipses strengthens Mr. Cowell's view, for it shows that his data serve to represent other eclipses besides those considered by him, and in particular that they serve to represent the eclipse of Larissa, the most critically important of them all. Indications of the existence of such a secular term, though smaller in amount, have been found cropping up repeatedly in the discussion of the early observations; but it is very difficult to differentiate such a secular term from the very similar effects which would be produced by inequalities of very long period in the complete expression for the Moon's latitude, and there is some reason for supposing these to exist.

A much wider question is raised by Mr. Cowell in his second paper, that the apparent secular acceleration of $+4''\cdot4$ in the angular distance of the Moon from its node really arises from the existence of a secular acceleration of $+4''\cdot1$ in the mean longitude of the Earth.

Assuming that the ancient eclipses of the Sun show that there exist a secular acceleration of $+4''\cdot4$ in the angular distance of the Moon from the node and a secular acceleration of $+6''\cdot8$ in the angular distance of the Moon from the Sun, Mr. Cowell points out that this can be represented by supposing the secular acceleration of the Moon's node to have the theoretical value of $+6''\cdot5$, and assigning a secular acceleration of $6''\cdot8+4''\cdot1=10''\cdot9$ to the mean longitude of the Moon, and of $+4''\cdot1$ to the apparent mean longitude of the Sun.

The effect of this change of origin of the secular acceleration leaves unchanged the epoch of conjunction of the mean longitudes of the Sun and Moon, and does not alter the values of either $D=(L-L')$ or $F=(L-\Omega)$; hence Mr. Cowell concludes that it leaves unchanged the figures of his eclipse calculations, except perhaps a small change of less than $20''$ in the correction for parallax, which he regards as quite unimportant.*

* This is an oversight of Mr. Cowell's. It is true that neither D nor F is altered, but both g and g' are changed by quantities which may exceed a degree of arc. Hence both V and V' and their difference V − V' may be changed by considerable quantities, possibly amounting to several hundreds of seconds of arc in the case of the earlier eclipses; whilst U will also be

But it will be seen that this new hypothesis as to the origin of the correction required by the Moon's argument of latitude removes one theoretical difficulty only at the expense of restoring another; for though the assumed secular acceleration of the Moon's node is brought into accord with theory, it is only at the cost of reinstating the discordance between $6''\cdot0$, the theoretical value of the secular acceleration in mean longitude, and that of $10''\cdot9$, the value necessitated by Mr. Cowell's new hypothesis. It is true that such a discordance conceivably might arise from tides in the body of the Earth, regarded as a thin rigid shell covering a viscous fluid interior, or in an ocean entirely covering the surface of the Earth, though not from tides in smaller oceans having the physical configuration of those actually existing on the terrestrial surface; but there is no real evidence in support of a tidal retardation in the rotation of the Earth of a nature which could be held to account for a material discordance between the observed value of the secular acceleration of the Moon's mean longitude and that derived by theory from the diminution in the eccentricity of the Earth's orbit.

The effect of this amended hypothesis for bringing the lunar tables into accord with the ancient eclipses by assuming the existence of a considerable secular acceleration in the motion of the Earth from the effects of a resisting medium in space proceeds far beyond the effect on the eclipses, but, except in respect of its effects on the observations of the transits of *Mercury*, these have not been considered by Mr. Cowell. It is not proposed, however, to discuss the matter beyond its effects on the apparent longitudes of the Sun and Moon, though these form a very small portion of the difficulties which would have to be overcome in reconciling with observation the effects due to this new hypothesis of Mr. Cowell's. The assumed secular retardation cannot be supposed to be confined merely to the Earth; so the assumed law of resistance in space must be such that, despite the great physical differences between the different planets, the apparent secular accelerations of the other planets would differ so slightly from the apparent secular acceleration of the Earth that no appreciable signs of the difference would be apparent. The more important cases would be those of *Venus* and *Mars*, whose observed secular variations are closely in accord with those derived from theory, and Mr. Cowell would have some difficulty in finding a law of resistance in space which would leave the relative motions of the three planets unaffected. The effects of the resisting medium would extend, of course, to the eccentricities as well as to the mean distances.

altered, though to a smaller degree. Hence Mr. Cowell's eclipse calculations will no longer apply, and must be revised to meet the effects of the changed hypotheses. In the case of the five particular eclipses considered by Mr. Cowell it is probable that small alterations in his data will suffice to bring them into accord with the changed conditions, and so leave his conclusions unaffected.

Restricting the consideration to the effects on the mean longitudes of the Sun and Moon, assuming 1900 as the epoch, the effect of the new secular term would be to increase the tabular longitudes by a second of arc in 1850, so it will be necessary to increase the secular mean motions by some two seconds of arc, in order to bring the new tabular places into the same accord with observation as exists with the present tables as revised. The effect will be to increase the tabular longitudes of the Sun and Moon at different epochs by the quantities given in column I. of the table which follows. But it will be seen that this leaves discordances of over 6″ between Bradley's observations of 1750–60 and the tables as altered, discordances far greater than are admissible; hence to bring these earlier observations into accord with the changed tables a still further increase must be made in the secular mean motion, with the consequence that if the ancient eclipses are still to be represented, a further increase must also be made in the value of the new secular acceleration. Adopting $+5''\cdot5$ for the centennial increase in the mean longitude and $+4''\cdot33$ for the coefficient of the new secular term, the tabular places of the Sun and Moon at the different epochs will be changed by the quantities shown in Column II. For comparison, the columns headed "Sun" and "Moon" show the outstanding discordances between the observed and latest revised tabular places of the Sun and Moon, and the columns "Sun + II." and "Moon + II." the residuals which will remain outstanding when compared with tables modified by the quantities given under Column II.

Epoch.	I.	II.	Sun.	Sun + II.	Moon.	Moon + II.
	″	″	″	″	″	″
1900	+ ·00	+ ·00	+ ·20	+ ·20	+ ·55	+ ·55
1880	− ·24	− ·93	− ·07	− 1·00	+ ·12	− ·81
1860	− ·14	− 1·51	− ·41	− 1·92	− ·04	− 1·55
1840	+ ·28	− 1·75	− ·45	− 2·20	− ·21	− 1·96
1820	+ 1·02	− 1·63	+ 1·11	− ·52	+ ·52	− 1·11
1800	+ 2·10	− 1·17	− ·72	− 1·89	− ·75	− 1·92
1780	+ 3·50	− ·37	− ·95	− 1·32	+ ·79	+ ·42
1760	+ 5·24	+ ·78	+ ·22	+ 1·00	− 1·70	− ·92
1740	+ 7·30	+ 2·28	+ ·30	+ 2·58	− 1·94	+ ·34
1720	+ 9·68	+ 4·12	...	...	− ·13	+ 3·99
1700	+ 12·44	+ 6·65	...	...	− ·39	+ 6·26
1680	+ 15·44	+ 8·85	...	...	+ 1·91	+ 10·74
1650	+ 18·81	+ 11·74	...	...	+ ·98	+ 12·72

The resulting discordances between the tabular and observed places of the Moon between 1740 and 1900 could be eliminated by an increase in the assumed coefficients of the terms of very long period arising from the perturbations by the planets, but it

is doubtful if the very large discordances between the observed and tabular times of the numerous occultations of stars observed between 1680 and 1730 could be similarly eliminated. But there is no such means of removing the discordances which the change would introduce between the observed and tabular places of the Sun during the period 1750–1880, and these discordances are far greater than can be ascribed to the outstanding errors of observation.

Natal Observatory:
1906 *April* 3.

On the Ratios of the triangles in the Determination of the Elliptic Orbit from three Observations. By Shin Hirayama.

1. In this paper I determine the ratios of the triangles which play an important part in the problem of determining the orbit from three observations. Gibbs has determined these ratios by expanding the heliocentric rectangular coordinates of the planet in powers of time, while I expand them in a series of sines and cosines of the mean anomaly and in powers of eccentricity, as is generally done in the elliptic theory.

2. For the three observations of the planet at the times t_1, t_2, and t_3 we have :

$$t_3-t_2=\tau_1. \qquad t_3-t_1=\tau_2. \qquad t_2-t_1=\tau_3.$$

$\left.\begin{matrix} x_1, y_1, z_1 \\ x_2, y_2, z_2 \\ x_3, y_3, z_3 \end{matrix}\right\}$ three rectangular heliocentric coordinates of planet.

r_1, r_2, r_3 radii vectores of planet.

n mean daily motion expressed in seconds of arc.

a semi-major axis of planet.

3. Let

$$x=a_0+a_1\sin nt+b_1\cos nt+a_2\sin 2nt+b_2\cos 2nt \quad . \quad . \quad (1)$$

where a_0, a_1, b_1, a_2, b_2, are five constants depending on the elements of the orbit. Then the accelerations along the x axis corresponding to the three positions will be represented by the following expressions respectively :

For $t=-\tau_3$; $\dfrac{d^2x}{dt^2}=-\dfrac{x_1}{r_1^3}=-n^2a_1\sin n\tau_3+n^2b_1\cos n\tau_3-4n^2a_2\sin 2n\tau_3+4n^2b_2\cos 2n\tau_3$

For $t=0$; $\dfrac{d^2x}{dt^2}=-\dfrac{x_2}{r_2^3}=\qquad n^2b_1 \qquad +4n^2b_2$

For $t=+\tau_1$; $\dfrac{d^2x}{dt^2}=-\dfrac{x_3}{r_3^3}=+n^2a_1\sin n\tau_1+n^2b_1\cos n\tau_1+4n^2a_2\sin 2n\tau_1+4n^2b_2\cos 2n\tau_1$

Hence we have

$$\begin{aligned}
x_1 &= a_0 - a_1 \sin n\tau_3 + b_1 \cos n\tau_3 - a_2 \sin 2n\tau_3 + b_2 \cos 2n\tau_3 \\
x_2 &= a_0 \qquad\qquad\quad + b_1 \qquad\qquad\qquad\qquad\quad + b_2 \\
x_3 &= a_0 + a_1 \sin n\tau_1 + b_1 \cos n\tau_1 + a_2 \sin 2n\tau_1 + b_2 \cos 2n\tau_1 \\
\frac{x_1}{n^2 r_1^3} &= \quad - a_1 \sin n\tau_3 + b_1 \cos n\tau_3 - 4a_2 \sin 2n\tau_3 + 4b_2 \cos 2n\tau_3 \\
\frac{x_2}{n^2 r_2^3} &= \qquad\qquad\quad + b_1 \qquad\qquad\qquad\qquad\quad + 4b_2 \\
\frac{x_3}{n^2 r_3^3} &= \quad + a_1 \sin n\tau_1 + b_1 \cos n\tau_1 + 4a_2 \sin 2n\tau_1 + 4b_2 \cos 2n\tau_1
\end{aligned}$$

From these six equations the five constants a_0, a_1, b_1, a_2, b_2 may be eliminated, leaving an equation of the form

$$\left.\begin{aligned}
&\left[4(S_2 \sin n\tau_1 - S_1 \sin 2n\tau_1) + \frac{4S_1 \sin 2n\tau_1 - S_2 \sin n\tau_1}{n^2 r_1^3}\right] x_1 \\
&\quad + \left[4(S_2 \sin n\tau_2 - S_1 \sin 2n\tau_2) + \frac{4S_1 \sin 2n\tau_2 - S_2 \sin n\tau_2}{n^2 r_2^3}\right] x_2 \\
&\qquad + \left[4(S_2 \sin n\tau_3 - S_1 \sin 2n\tau_3) + \frac{4S_1 \sin 2n\tau_3 - S_2 \sin n\tau_3}{n^2 r_3^3}\right] x_3 = 0
\end{aligned}\right\} \quad \ldots (2)$$

where

$$S_1 = \sin n\tau_1 + \sin n\tau_2 + \sin n\tau_3 = -4 \sin \frac{n\tau_1}{2} \sin \frac{n\tau_2}{2} \sin \frac{n\tau_3}{2}$$

$$S_2 = \sin 2n\tau_1 + \sin 2n\tau_2 + \sin 2n\tau_3 = -4 \sin n\tau_1 \sin n\tau_2 \sin n\tau_3$$

If we put

$$\left.\begin{aligned}
S &= \cos \frac{n\tau_1}{2} \cos \frac{n\tau_2}{2} \cos \frac{n\tau_3}{2} \\
P_1 &= 4S - \cos n\tau_1 = 1 + \cos n\tau_2 + \cos n\tau_3 \\
P_2 &= 4S - \cos n\tau_2 = 1 + \cos n\tau_3 + \cos n\tau_1 \\
P_3 &= 4S - \cos n\tau_3 = 1 + \cos n\tau_1 + \cos n\tau_2 \\
Q_1 &= \cos n\tau_1 - S = 3S - P_1 \\
Q_2 &= -\cos n\tau_2 + S = -3S + P_2 \\
Q_3 &= \cos n\tau_3 - S = 3S - P_3
\end{aligned}\right\} \quad \ldots \quad \ldots \quad (3)$$

then we easily derive from (2) the following equation:

$$\sin n\tau_1 \left(P_1 + \frac{Q_1}{n^2 r_1^3}\right) x_1 - \sin n\tau_2 \left(P_2 - \frac{Q_2}{n^2 r_2^3}\right) x_2 + \sin n\tau_3 \left(P_3 + \frac{Q_3}{n^2 r_3^3}\right) x_3 = 0 \quad \ldots (4)$$

Whence we see that the three triangles determined each by a pair of the three radii vectores, and usually denoted by $[r_2r_3]$, $[r_1r_3]$, $[r_1r_2]$, are respectively proportional to

$$\left(P_1+\frac{Q_1}{n^2r_1^3}\right)\sin n\tau_1,\quad \left(P_2-\frac{Q_2}{n^2r_2^3}\right)\sin n\tau_2,\quad \left(P_3+\frac{Q_3}{n^2r_3^3}\right)\sin n\tau_3 \qquad (5)$$

4. Expand S, P_1, Q_1, &c. in powers of τ, and neglect the higher powers of τ. Substituting all these values in (4), and after dividing by common factors, we get the equation

$$\tau_1\left(1+\frac{\tau_2\tau_3-\tau_1^2}{12r_1^3}\right)x_1-\tau_2\left(1-\frac{\tau_1\tau_3+\tau_2^2}{12r_2^3}\right)x_2+\tau_3\left(1+\frac{\tau_1\tau_2-\tau_3^2}{12r_3^3}\right)x_3=0$$

which is the equation first obtained by Gibbs.

5. In the above explained method for the determination of the ratios of triangles we assume a suitable value of n, and compute these ratios by (3) and (5). We find thus a very close approximation to their correct values if the eccentricity of the ellipse be small. The starting equation (1) shows that there we have already neglected certain terms of the squares of eccentricity.

6. To test the accuracy of the preceding formulæ let us take the *Ceres* example treated by Gauss. The ratios of triangles are computed for four different values of n; while the rigorous values of $[r_2r_3]$, $[r_1r_3]$, and $[r_1r_2]$ are computed by the expressions $r_2r_3\sin(v_3-v_2)$, $r_1r_3\sin(v_3-v_1)$, and $r_1r_2\sin(v_2-v_1)$ respectively. The results are shown in the following table, the corresponding values from Oppolzer and Gibbs being added for comparison.

	$\log\frac{[r_2r_3]}{[r_1r_3]}$.	Error.	$\log\frac{[r_1r_2]}{[r_1r_3]}$.	Error.
Rigorous Formula	9·751242	0	9·776875	0
Oppolzer's „	9·742730	+8512	9·768466	+8409
Gibbs' „	9·751316	− 74	9·776953	− 78
Hirayama's Formula $n=$ 1000″	9·751122	+120	9·777070	− 95
769·6845	9·751280	+ 38	9·776859	+ 16
750	9·751287	− 45	9·776853	+ 22
500	9·751323	− 81	9·776864	+ 9

Astronomical Observatory, Azabu, Tōkyō:
1906 *March* 19.

On the Orbit and Relative Masses of β 733 (85 *Pegasi*). By W. Bowyer and H. H. Furner.

β 733.

R.A.	$23^h\ 56^m\ 57^s$	} 1900	Mags. 6 : 10
N.P.D.	$63°\ 27'$		

The discussion of the meridian observations of 85 *Pegasi* for a determination of the relative masses, incidentally showed that the period of this binary did not exceed twenty-five years.

The orbit has been computed at various times, the results so far as the period is concerned being—

	Years.
1888 Schaeberle...	22·3
1892 Glasenapp	17·5
1895 See...	24·0
1899 Burnham	25·7

This failure to secure harmony has led to a discussion of the micrometer measures, which are best satisfied by a period of twenty-six years—*i.e.* a little larger than that deduced by Professor Burnham.

The meridian observations extend over a period of seventy-five years, or three revolutions, and the period given can be assumed to be more accurate than that at present derived from the micrometer measures. One explanation of the discrepancy may be found in the difficulty of measuring so close and dissimilar a pair; but there is a tendency to periods of alternate positive and negative residuals when comparing observed and computed places which would point to some real disturbing cause. This would show to a greater extent in the micrometer measures than in the meridian observations.

In Fig. 1 all available measures have been taken in groups, plotted down, and the apparent ellipse drawn. From this the elements of the true ellipse have been found to be :—

$e = \cdot 46$	$a = 0''\cdot 82$
$\Omega = 115°\ 38'$	$T = 1883\cdot 5$
$\gamma = 53\ \ 5$	$P = 26\cdot 3$ years
$\lambda = 266\ \ 7$	

From the apparent ellipse the relative movement of the two components is found to be $1''\cdot 35$ in right ascension and $1''\cdot 05$ in

north polar distance, these being the values used in the following discussion of the masses.

Several more years' micrometer measures would appear desirable before a really satisfactory investigation of the system can be made. Of late, observations of the pair are somewhat scarce, but double-star observers would do well to keep this binary under careful measurement for some time to come.

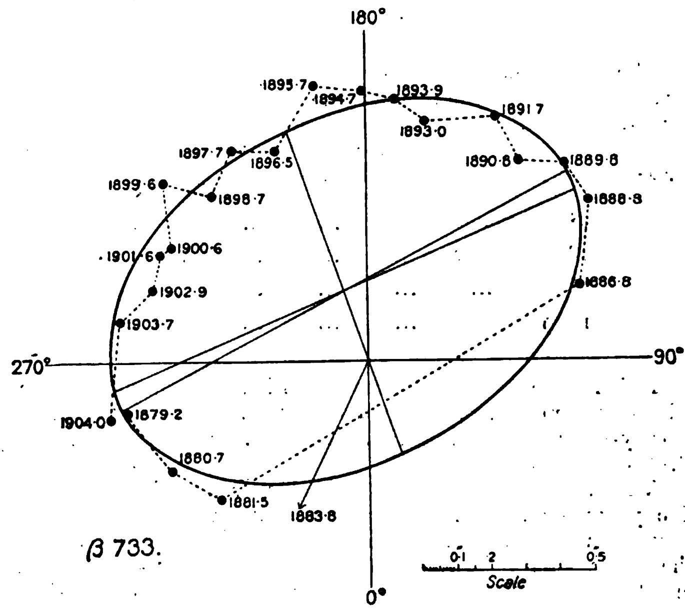


FIG. 1.—Apparent Ellipse.

On the Mass of 85 *Pegasi.*

The system 85 *Pegasi* consists of a sixth-magnitude star whose colour is yellow, and a tenth-magnitude star whose colour is blue. It is a close pair, but the great difference in brightness allows us to assume that the meridian observations are of the bright component, or that the effect of the faint companion on the bisections may be neglected. The following observations have been corrected by Auwers' corrections and for proper motion.

The observations extend over a period of seventy-five years, and so actually date two complete revolutions anterior to the discovery of the faint companion by Burnham in 1878. A very good determination of the period is therefore possible. It may be taken as 24·5 years. The meridian observations give a range

of $1''\cdot15$ in R.A., and $0''\cdot8$ in N.P.D. (see fig. 2), corresponding to a range of $1''\cdot35$ and $1''\cdot05$ in the relative orbit, and hence

$$\frac{\text{Mass A}}{\text{Mass B}} = \frac{1\cdot35 - 1\cdot15}{1\cdot15} = \frac{4}{23} \text{ from R.A.}$$

and

$$= \frac{1\cdot05 - 0\cdot8}{\cdot8} = \frac{5}{16} \text{ from N.P.D.}$$

giving equal weight to each, the mass of the faint star is approximately four times that of the bright star.

Right Ascensions and North Polar Distances of 85 *Pegasi reduced to the Epoch* 1900·0 *with Auwers' Systematic Corrections applied. Adopted Proper Motions.*

+0s·0612 *in R.A. and* +0″·980 *in N.P.D.*

Cat.	Epoch of Obs. R.A.	No. of Obs.	Secs. R.A. 1900·0.	Epoch of Obs. N.P.D.	No. of Obs.	Secs. N.P.D. 1900·0.
			s			″
Argelander ...	1830	11	56·77	1830	11	50·3
Armagh ...	1831·6	6	56·70	1846·2	7	48·1
Taylor ...	1835·4	10	56·72	1836·5	10	50·2
Rumker ...	1845·0	3	56·67	1845·0	3	48·4
Paris	1849·8	2	56·82	...	...	...
Radcliffe ...	1857·3	4	56·76	1860·1	3	51·8
Brussels ...	1860·8	25	56·71	1857·5	18	50·4
Paris	1864·1	21	56·74	1861·8	2	49·6
Greenwich ...	1866·2	3	56·64	1866·2	3	49·8
Paris	1871·9	2	(56·82)	1871·8	1	49·5
Greenwich ...	1873·6	5	56·67	1873·9	7	49·8
Camb. (Eng.)...	1874·0	4	56·71	1874·0	4	49·6
Romberg ...	1875·3	5	56·74	1875·3	5	49·6
Greenwich ...	1882·1	3	56·72	1881·3	4	50·5
Washington ...	1885·2	15	56·70	1885·2	15	49·5
Dunsink ...	1886·2	4	56·67	1886·2	4	50·3
Cincinnati ...	1889·8	4	56·64	1889·8	4	50·0
Glasgow ...	1891·9	2	56·78	1891·9	2	49·8
Greenwich ...	1894·7	17	56·72	1894·4	20	49·8
Greenwich ...	1897·0	1	(57·00)	1897·0	1	50·9
Cincinnati ...	1899·8	3	56·72	1899·8	3	49·2
Greenwich ...	1905·8	4	56·77	1905·7	4	50·0

The relative masses may be derived in a different manner. Besides the two stars A and B which make up the binary, there is a third star, C, of the ninth magnitude, whose position with respect to A has been repeatedly measured. Its apparent motion

with respect to A for the last fifty years is exactly equal and opposite to the proper motion of A, and may therefore be considered as fixed in the sky. If, however, the star A has an orbital motion, the apparent motion of C, instead of being equal and rectilinear from year to year, should be affected by this change of position of A. The measures may be treated in two ways; but in each method it is first requisite to change the polar coordinates θ and ρ into differences of right ascension and declination. This being done we may correct for proper motion of A and solve the equations

$$\rho' . \cos\theta' = c\rho . \cos\theta + \Delta\delta$$
$$\rho' . \sin\theta' = c\rho . \sin\theta + \Delta\alpha$$

where ρ and ρ' are distances of B and C from A
θ „ θ' „ position-angles „ „ „
$\Delta\alpha$ „ $\Delta\delta$ „ differences „ R.A. and Decl. of C and the centre of gravity of A and B

and $c\rho$ is the distance of A from the centre of gravity.

	Position-angle.	Distance.	Diff. R.A. reduced to 1900.	Diff. N.P.D. reduced to 1900.
	°	″	″	″
1851·96	114·1	33·03	9·77	33·58
52·67	113·9	32·60	9·49	33·13
65·91	92·1	18·89	9·43	32·72
68·77	82·4	17·03	9·04	32·83
69·98	77·8	16·13	9·23	32·86
70·65	74·4	15·47	9·45	32·89
74·66	54·4	13·92	9·71	32·91
76·77	40·3	14·02	10·22	33·43
77·94	39·8	14·00	9·36	32·36
78·54	33·6	14·40	9·87	33·03
78·74	32·8	14·76	9·64	33·24
79·27	30·4	14·96	9·65	33·23
80·57	25·0	15·41	9·64	33·01
81·61	20·6	16·34	9·51	33·32
82·73	16·7	17·25	9·38	33·45
83·54	11·3	17·34	[10·25]	33·16
86·24	7·6	19·84	8·74	33·17
86·99	6·1	21·15	8·78	33·78
88·67	0·9	21·71	9·05	32·77 }
89·61	358·6	22·69	9·28	32·86 }
90·52	356·7	23·59	9·45	32·83

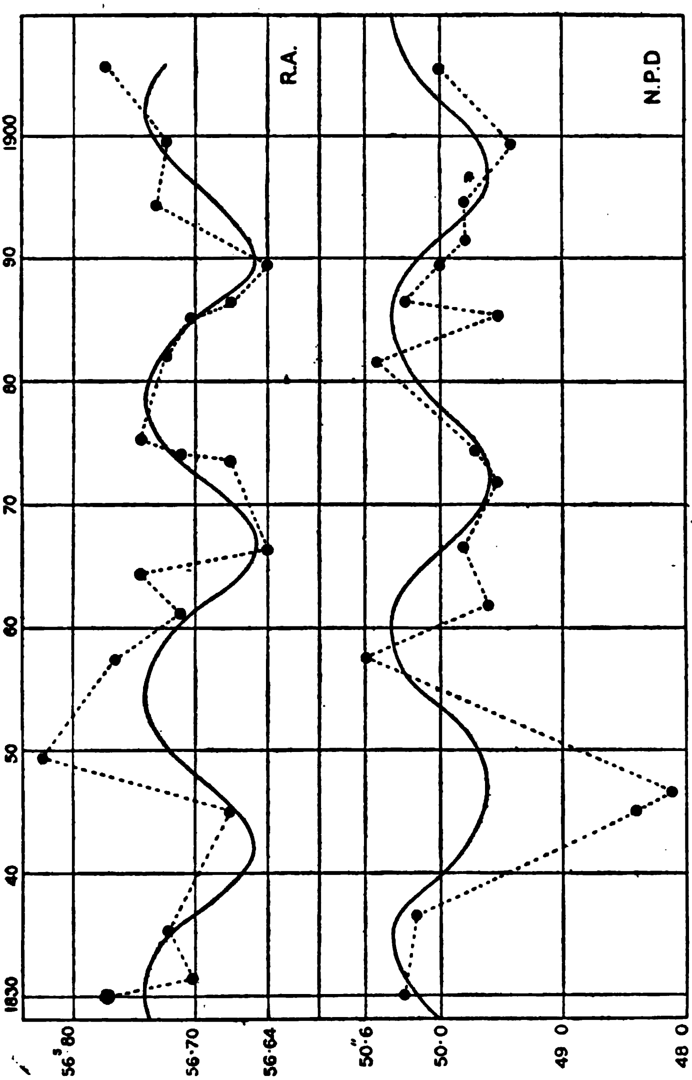


FIG. 2.—Diagram showing R.A.s and N.P.D.s of 85 *Pegasi* from T.C. Observations.

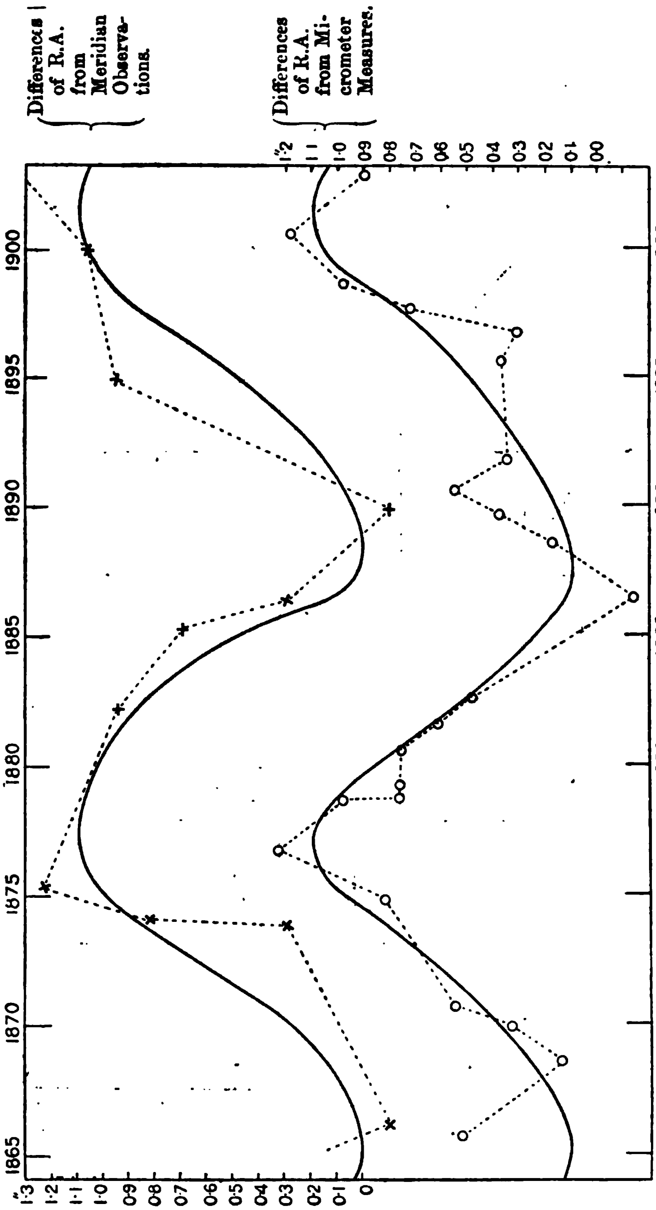


FIG. 3.—Comparison of Meridian and Micrometer Places of 85 *Pegasi.*

	Position-angle.	Distance.	Diff. R.A. reduced to 1900.	Diff. N.P.D. reduced to 1900.
	°	"	"	"
1891·84	354·4	24·90	9·25	32·78
95·53	349·0	29·17	9·27	33·01
96·75	347·8	30·48	9·20	32·98
97·69	345·9	31·62	9·62	32·93
98·57	344·4	32·68	9·86	32·92
1900·66	342·9	35·15	9·74	32·97
00·86	342·3	36·60	10·41	34·03
02·73	341·3	37·64	9·79	32·98

The graphical method has, however, the advantage of exhibiting more clearly the movement of the principal star. The corrected differences of right ascension and declination are disposed in two curves, and the amplitude of the curves compared with the similar extent of change in the apparent orbit. These two curves are not given, but the third diagram shows the R.A. curve and the corresponding portion of the first curve in fig. 2 to show the close agreement.

Thus if 1"·35 be the extent in R.A. of the relative orbit and 1"·00 be the extent in R.A. of the difference in R.A., we have

$$\frac{1·35-1·00}{100} = \frac{7}{20} = \frac{\text{Mass A}}{\text{Mass B}}$$

from the right ascension differences, and similarly

$$\frac{1·05-0·75}{·75} = \frac{2}{5} = \frac{\text{Mass A}}{\text{Mass B}}$$

from the N.P.D., giving equal weight to each ; then

$$\frac{\text{Mass A}}{\text{Mass B}} = \frac{3}{8}$$

Incidentally it gives the period of 85 *Pegasi* as 24·0 years, a result deserving of equal confidence with that derived from direct measures of A and B.

The star C was employed by Brünnow to determine the parallax of 85 *Pegasi*, which he found to be 0"·054.

The parallax according to Flint is 0"·03. Spectrum, D.C. 1890—E (Type II.).

New Double Stars. By the Rev. T. E. Espin, M.A.

The Spring has been unusually good for observing; not only have there been a great number of fine nights, but the definition has been, on the whole, excellent. The stars are entirely situated between 30° and 40° N. declination.

No.	B.D.	R.A. 1900.		Decl.		P.	D.	Mags.		Date.	Nights.	
	°	h	m	°	′	°	″					
270	35, 436	2	10·4	+36	0	358·8	2·95	9·2	12·0	06·98	2	BC
						343·7	42·35	...		06·98	2	AB
271	34, 459		26·7	34	48	66·4	1·26	9·5	10·0	06·79	1	
272	35, 551		40·2	35	54	77·0	3·55	9·1	10·5	06·83	2	
273	34, 633	3	16·7	35	0	356·4	2·81	9·1	9·1	06·09	2	
274	...		22·1	35	37	142·4	3·18	9·3	9·4	06·11	3	
275	36, 737		36·3	36	49	297·9	3·41	9·3	10·2	06·13	3	
276	37, 819		37·3	37	40	282·8	7·81	8·0	13·8	06·14	3	
277	34, 741		43·8	34	31	289·7	7·40	10·0	14·0	06·09	2	BC
						142·5	30·24	A=	7·0	06·09	2	AB
278	39, 937	4	2·4	39	54	168·8	1·98	7·7	9·2	06·14	3	
279	34, 866		15·9	35	1	242·6	3·24	9·2	11·2	06·82	2	
280	39, 1201	5	4·9	39	49	302·8	3·19	9·0	10·5	06·14	1	
281	40, 1254		13·5	40	13	215·4	2·29	9·0	9·6	06·14	2	
282	...		21·7	33	44	114·6	1·99	9·1	10·3	06·09	3	
283	39, 1407		39·9	39	56	S.	2±	9·5	9·8	06·13	1	
284	37, 1345		46·5	37	24	184·4	4·73	9·0	11·0	06·07	1	
285	38, 1375		59·6	38	55	167·4	2·33	9·0	9·3	06·15	2	
286	39, 1550	6	6·9	39	45	64·0	2·83	9·0	9·5	06·15	2	
287	37, 1476		12·6	37	21	255·5	6·05	9·0	12·5	06·15	1	
288	39, 1600		14·9	39	11	148·9	4·40	9·0	9·3	06·16	1	AB
						273·8	13·42	C=	12·0	06·16	1	AC
289	39, 1825		55·9	39	6	98·9	1·97	9·4	9·7	06·18	2	
290	36, 1606	7	14·4	36	55	312·4	4·74	9·2	10·0	06·10	3	
291	32, 1667		56·4	32	17	343·4	7·12	8·5	10·2	06·19	2	
292	38, 3876	8	4·9	38	24	165·7	2·50	8·5	9·1	06·18	2	
293	32, 1705		10·5	32	34	214·6	4·76	9·0	9·4	06·22	2	
294	36, 1873		42·8	36	31	162·5	1·70	9·0	9·2	06·11	2	
295	35, 1874		42·8	35	21	306·8	3·58	9·1	11·5	06·74	3	
296	36, 1932	9	6·2	36	47	123·3	1·83	11·5	12·5	06·13	2	BC
						174·2	19·88	A=	8·2	06·13	2	AB
297	39, 2241		18·9	39	11	40·1	3·60	8·6	10·7	06·15	2	
298	39, 2242		19·4	+39	2	308·7	7·89	8·8	11·2	06·17	2	AB

No.	B.D.	R.A. 1900. h m	Decl. ° ′	P. °	D. ″	Mags.		Date.	Nights.	
298	39, 2242	9 19·4	+39 2	169·9	3·71	10·0	11·0	06·17	2	CD
				318·9	92·17	....		06·17	2	AC
299	35, 2017	25·8	34 56	217·1	4·78	11·2	11·5	06·26	2	BC
				360·0	55·87	A =	9·0	06·26	2	AB
300	35, 2021	27·6	35 36	142·4	2·04	9·2	10·3	06·27	2	
301	40, 2245	36·5	40 45	236·4	4·23	8·7	10·7	06·19	2	
302	37, 2077	10 20·6	36 58	348·4	2·63	9·2	10·7	06·17	2	
303	31, 2212	53·3	31 10	201·4	7·56	9·0	11·0	06·29	2	
304	39, 2399	55·0	39 1	89·1	5·65	9·2	10·5	06·19	2	
305	35, 2230	11 12·0	35 1	31·8	3·83	9·1	9·5	06·26	3	
306	39, 2458	33·0	39 18	341·0	6·76	8·0	11·2	06·25	2	
307	39, 2491	12 0·1	39 24	358·7	4·74	8·0	13·3	06·29	4	
308	32, 2343	13 16·5	32 30	292·2	7·06	9·1	9·1	06·28	3	
309	32, 2381	39·9	32 4	133·9	1·88	9·2	9·5	06·29	3	
310	32, 2382	40·2	31 57	nf	5 ±	9·2	11·0	06·27	1	
311	35, 2619	14 50·2	+34 52	288·5	3·76	8·8	9·3	06·28	2	

Notes.

271. This star was looked at again on February 9, but the condition of the air was then unsteady, and the star was not seen double.

278. A fine object, which so far has escaped detection.

282. This pair was found while measuring S 483. It is 187″ distant from B of S 483 at an angle of 30°·9.

289, 290. Angles discordant.

296. A difficult object found while measuring *h* 2483.

303. Found while measuring Σ 1492, rej. 1ᵐ 10ˢ *f.*

307. Found while looking for the missing pair *h* 2595. The *comes* is extremely difficult, and can only be seen by oblique vision.

Elements of Five Long-period Variable Stars.
By A. Stanley-Williams.

As the under-mentioned five long-period variable stars have now been under observation for several years, it seems desirable to bring together the results and to derive from them fresh and more exact elements of variation. Excepting where otherwise mentioned the dates of the different maxima and minima have been derived from observations made at Hove. Some further particulars of most of these have been published in the *Astronomische Nachrichten* or the *Astronomical Journal.* With the exception of *RU Persei* the minima of all the stars are too faint for observation with a 6½-inch telescope. *Z Lyræ*, however, does not descend much below the *minimum visibile* for this aperture.

Z Lyræ (*Ch.* 6816).

R.A. = $18^h\ 55^m\ 59^s$, Decl. = $+34°\ 48'\cdot9$ (1900).

Maxima of this star have been observed as under :

E.	Date.	J.D. 241+	Computed Maximum.	O−C. d	Mag.
−1	1899 Nov. 21 ±	4980 ±	4976·3	+3·7	...
0	1900 Sept. 2	5265	5267·3	−2·3	...
+1	1901 June 20*	5556	5558·3	−2·3	...
1	1901 July 1	5567	5558·3	+8·7	9·4
2	1902 Apr. 7 ±	5847 ±	5849·3	−2·3	...
4	1903 Nov. 10	6429	6431·3	−2·3	9·6
5	1904 Aug. 30	6723	6722·3	+0·7	9·3
6	1905 June 17	7014	7013·3	+0·7	9·9

and from these the following elements have been derived :

$$\text{Maximum} = \begin{Bmatrix}\text{1900 Sept. 4·3}\\ \text{J.D. 2415267·3}\end{Bmatrix} + 291^d\cdot0\ \text{E}.$$

The computed times of maximum and the residuals O−C are given in the fourth and fifth columns of the above table. It should be mentioned that there is a faint star ($12\frac{1}{2}$ mag.) about 12″ n.f. the variable, and easily mistaken for the latter when faint. The minimum brightness of *Z Lyræ* is probably about 14th magnitude.

RU Lyræ (*Ch.* 6895).

R.A. = $19^h\ 9^m\ 6^s$, Decl. = $+41°\ 8'\cdot1$ (1900).

Observed Maxima.

E.	Date.	J.D. 241+	Computed Maximum.	O−C. d	Mag.
2	1902 Aug. 21	5983	5987·2	−4·2	9·9
3	1903 Sept. 5	6363	6355·4	+7·6	9·4
4	1904 Aug. 28	6721	6723·6	−2·6	10·9
5	1905 Sept. 2	7091	7091·8	−0·8	10·2

The elements of variation are :

$$\text{Maximum} = \begin{Bmatrix}\text{1900 May 10·8}\\ \text{J.D. 2415250·8}\end{Bmatrix} + 368^d\cdot2\ \text{E}.$$

* Observed by Hartwig at Bamberg (*A. N.* 3744, col. 370).

TY Cygni (*Ch.* 7019).

R.A. = $19^h\ 29^m\ 51^s$, Decl. = $+28°\ 6'{\cdot}2$ (1900).

Observed Maxima.

E.	Date.	J.D. 241+	Computed Maximum.	O−C. d	Mag.
0	1900 Nov. 22 ±	5346 ±	5342·0	+4·2	...
1	1901 Nov. 11	5700	6995·8	+4·2	9·2
2	1902 Oct. 27	6050	6049·6	+0·4	8·85
3	1903 Oct. 7	6395	6403·4	−8·4	8·7
4	1904 Oct. 10	6764	6757·2	+6·8	9·1
5	1905 Sept. 19	7108	7111·0	−3·0	8·6

The following elements of variation have been derived from the foregoing maxima :

$$\text{Maximum} = \begin{Bmatrix} \text{1900 Nov. 18} \\ \text{J.D. 2415342} \end{Bmatrix} + 353^{d}{\cdot}8\ \text{E},$$

and these elements accord with the invisibility of the star on a photograph taken by Professor Max Wolf at Heidelberg on the nights of 1891 September 25–30 (total exposure 12 hours), as it should then have been near minimum brightness. The variable remains below 12th magnitude for nearly half the time.

TW Cygni (*Ch.* 7571*a*).

R.A. = $21^h\ 1^m\ 45^s$, Decl. = $+29°\ 0'{\cdot}3$ (1900).

Observed Maxima.

E.	Date.	J.D. 241+	Computed Maximum.	O−C. d	Mag.
−1	1899 Oct. 7 ±	4935 ±	4949·2	−14·2	...
+1	1901 Sept. 1	5629	5633·4	− 4·4	8·8
2	1902 Aug. 15	5977	5975·5	+ 1·5	9·6
3	1903 Aug. 3	6330	6317·6	+12·4	9·0
4	1904 June 28	6660	6659·7	+ 0·3	9·2
5	1905 May 26	6992	7001·8	− 9·8	9·0

The elements of variation are :

$$\text{Maximum} = \begin{Bmatrix} \text{1900 Sept. 28·3} \\ \text{J.D. 2415291·3} \end{Bmatrix} + 342^{d}{\cdot}1\ \text{E}.$$

The residuals in the fifth column indicate that the period is subject to a somewhat large irregularity, doubtless of a periodic character, though the observations do not yet extend over a sufficiently long interval of time to enable any accurate value of it to be derived.

RU Persei.

R.A. = $3^h\ 23^m\ 57^s$, Decl. = $+39°\ 18'.9$ (1900).

Observed Maxima.

E.	Date.	J.D. 241+	Computed Maximum.	O—C.	Mag.
				d	
0	1904 Nov. 28	6813	6814·0	−1·0	9·7
2	1905 Nov. 26	7176	7175·4	+0·6	9·4

Observed Minima.

E.	Date.	J.D. 241+	Computed Minimum.	O—C.	Mag.
0	1904 Sept. 19	6743	6743·0	0·0	10·7
2	1905 Sept. 17	7106	7104·4	+1·6	10·4
3	1906 Mar. 14	7284	7285·1	−1·1	10·6

The adopted elements of variation derived from the above maxima and minima are:

$$\text{Maximum} = \begin{Bmatrix} 1904 \text{ Nov. } 29 \\ \text{J.D. } 2416814 \end{Bmatrix} + 180^d\!.7\ E,$$

the interval M—*m* being 71 days. The magnitude of the variable at maximum is 9·4–9·7; and at minimum it is 10·4–10·7.

Owing to the small range of variation, and to the fact that both the maximum and minimum brightness vary somewhat, I have not attempted to correct the above elements by means of the photographic observations published in the *A. N.* 3675. For the same reason the early B.D. observations published by Professor Küstner in the *A. N.* 3989 are not at present available for this purpose. Dr. E. Hartwig observed the star equal to B.D. $+39°.803$ (9·5 mag.) on 1905 October 20 (*A. N.* 4061). According to the observations made here it attained to equality with that star on 1905 October 19.

20 Hove Park Villas, Hove:
1906 *May* 1.

Observations of Jupiter in 1903 *and* 1905–6. By W. F. Denning.

In *Monthly Notices*, lxiii. 331–4 (1903 April), I gave a summary of rotation periods of markings on *Jupiter* from observations at Bristol during the years 1898 to 1902 inclusive.

In continuation of these results I give the following table for the opposition of 1903:—1388 transits were taken and 1188 of these were utilised in the determination of rotation periods:

1903.

Markings.	Rotation Period. h m s	No. of Spots.	Mean No. Rotations.
N.N. Temperate	9 55 41·1	14	217
N. Temperate	9 55 54·3	9	291
N. Tropical	9 55 31·9	3	336
Equatorial	9 50 27·9	28	561
S. Tropical	9 55 43·0	2	141
Great Red Spot	9 55 41·6	1	608
Great S. Tropical	9 55 18·7	1	548
S. Temperate	9 55 18·5	9	320
S.S. Temperate	9 55 6·0	1	210

In 1904 I made very few observations in consequence of bad health, but resumed work on *Jupiter* at midsummer 1905, and continued it until the planet approached too near to the Sun (in 1906 May) for further effective observation.

1905–6.

Markings.	Rotation Period. h m s	No. of Spots.	Mean No. Rotations.
N. Tropical	9 55 55·2	1	58
Equatorial	9 50 32·7	24	448
Great Red Spot	9 55 41·5	1	761
Great S. Tropical	9 55 19·5	1	507 P end
" "	9 55 23·6	1	641 F end
S. Temperate	9 55 20·3	7	353

Notes on the Apparition of 1905–6.

N.N.N. Temperate Spots.—There were signs of considerable disturbance in the region far north, about 40°–65°, and extensive irregularities in the N.N.N. Temperate Belt and N. Polar Cap were visible. These consisted of large white spots with very dark areas adjoining. A number of transits were taken, but they were insufficient to render the identifications certain and to enable perfectly safe rotation periods to be derived.

N.N. Temperate and N. Temperate Belts.—Very faint and only just traceable as delicate pencil-like shadings.

N. Tropical Spot.—This was discovered on 1906 April 10, and probably represented an extensive disturbance which had occurred only a few days previously; for I had examined the same region on April 3 and 7 without noticing anything unusual. When first seen the spot was very dark and distinct, and formed the *f* extremity of a slanting belt running to W.S.W. from the spot and joining the N. Equatorial Belt. Contemporary with

this disturbance the N. Equatorial Belt, which in previous months had been extremely feeble, exhibited signs of rapid development, and especially in that region *p* the N. Tropical Spot and N. of the Great Red Spot. But the changes referred to, occurring, as they did, near the close of the apparition, could only be followed during a comparatively short interval (April 10 to May 4). The longitude of the N. Tropical Spot increased from 75° to 80° (System II.) in the twenty-four days included in the period alluded to, becoming increasingly conspicuous, so that it could be as definitely observed as a satellite-shadow, and was readily visible at mid-transit on April 20 at $5^h\ 22^m$, nearly two hours before sunset. Its rotation period was about 14 seconds longer than that of the Red Spot, and it evidently participated in the motion of the N. Temperate current rather than in that of the usual N. Tropical Spots, which rotate in about 10 seconds less time than the Red Spot.

Equatorial Spots.—These consisted of the normal white and dark markings alternating on the N. side of the Great S. Equatorial Belt. Their mean period of rotation proved to be a few seconds in excess of the rate exhibited during the previous eight years.

Great Red Spot.—This appeared very faint and indefinite except under very sharp definition, when its oval outlines could be distinctly traced. The motion was a little irregular, but the spot was certainly not accelerated in any striking degree, when the Great S. Tropical Spot closely approached its eastern side. The junction of the *f* end of Red Spot with *p* end of the S. Tropical Spot occurred on about March 5, for no division between them could be remarked on that date.

Great S. Tropical Spot.—A transit of the ends of this extensive disturbance, obtained on 1905 August 7, indicated its length as 43°·5, but a rapid distension thereafter occurred, for on September 13 the length was 49°·6, and on October 19, 58°·6. A further increase was noted in ensuing months, but it was of relatively trifling character. This longitudinal growth of the marking evidently occurred at the following end; for while the *p* end rotated at the normal rate, the *f* end showed a considerable retardation, the period being 4 seconds greater. The dark material of the fore part of the Spot was passing S. of the Red Spot in March and April, and the dark front of the former was not due on the *p* side of the latter until about the middle of 1906 May; but as early as April 19 there was a dusky patch extending from 351° to 11°, and well in advance of the Red Spot. I had observed this indistinctly on several previous occasions in April, but its feebleness caused me to question its relationship with the much darker aspect of the old S. Tropical Spot. If identity is assumed then its translation from the *f* to the *p* side of the Red Spot must have been exceedingly rapid and fully bears out the suggestion of Major P. B. Molesworth (*Monthly Notices*, lxvi. p. 102).

A brilliant white spot usually precedes the Great S. Tropical disturbance, and the former apparently passed round the *northern* side of the Red Spot. It was seen on 1906 February 21 N. *f* the Red Spot, and its longitude on four other nights was: March 5, 47°·8; April 12, 23°·2; April 19, 24°·1; April 29, 17°·1.

S. Temperate Spots.—As usual there were several large white spots fringing the S. border of the S. Temperate Dark Belt. Some of these markings appear to have existed for a long period, though little effort has been made to identify the same individual features during many successive apparitions. This, however, now admits of easy attainment from the abundance of materials accumulated in recent years. In *The Observatory*, 1904, September (vol. xxvii. p. 345), I gave some data with regard to two of these objects which had been followed during several years. They are still visible at the present time.

During the past apparition the S. Tropical Zone usually appeared to be the brightest region of the disc, whereas in 1903 the equatorial zone was more luminous than any other.

Observations of *Jupiter* in bright sunshine are sometimes very effective. On many occasions I have seen the principal markings beautifully defined at about 2^h or $1\frac{1}{2}^h$ before sunset. But the best time for examination of Jovian detail is near the time of sunset, when the spots and irregularities in the belts are often presented with remarkable distinctness. Whenever daylight observations of *Jupiter* are attempted care must be taken to protect the tube of the telescope from the direct rays of the Sun. Equatorial mounting is not necessary, as the planet can generally be swept up in very few minutes with a low-power eyepiece.

Several observers have reported an annoying prevalence of bad definition during the past winter, but this has been quite contrary to my experience. The high altitude of the planet, as compared with its comparatively low position in the few previous years, has favourably influenced the character of the seeing, for my figures for 1903 and 1905–6 are:—

	Nights of Observation.	Very Good.	Good.	Fair.	Bad.	Very Bad.
1903	109	9	21	21	40	18
1905–6	88	17	25	22	17	7

The instrument employed in 1903 was a 10-inch With-Browning reflector, power 312. In 1905–6 I also used a $12\frac{1}{2}$-inch Calver reflector, powers 200, 315, and 440.

Bishopston, Bristol:
1906 *May* 10.

Observation of Jupiter's Sixth and Seventh Satellites from Photographs taken with the 30-inch Reflector at the Royal Observatory, Greenwich, in 1905–6.—II.

(*Communicated by the Astronomer Royal.*)

In a preliminary paper in the *Monthly Notices* for 1905 November provisional results were given from the photographs obtained up to November 7. Further photographs of the sixth and seventh satellites have since been secured, and the more accurate method of measurement indicated in the preliminary note has been applied to the whole series.

As there explained, the positions of the satellites have been measured on the photographs taken with the reflector with reference to three or four faint comparison stars (of eleventh or twelfth magnitude) symmetrically distributed round the satellite. The positions of these faint comparison stars were then measured relatively to the reference stars (of eighth to ninth magnitude) in the Astronomische Gesellschaft Catalogue (Berlin Zone) from photographs (with 20 minutes' exposure) taken with the astrographic 13-inch refractor, the field sensibly free from distortion being much larger with this telescope than with the reflector, so that from twelve to sixteen reference stars were available on each plate.

As *Jupiter* moved slowly it was possible to make one reference plate serve for a number of photographs, which were each referred to it. The constants were determined in the usual manner, all the stars on the plate given in the Astronomische Gesellschaft Catalogues being used for the purpose. Right ascensions and declinations of the satellites were then determined and, by comparison with the tabular positions of *Jupiter*, position angles and distances deduced.

Ten photographs to determine the errors of the tabular place of *Jupiter* were taken between 1905 November 3 and 1906 February 15 with the Astrographic Equatorial. Corrections have been deduced from these, but the discussion is not yet complete. They show, however, that the errors of the tabular place of *Jupiter* are very small, and this result is confirmed by the observations with the transit circle and with the altazimuth.

Observations of Satellite VI.

Date and G.M.T.	Apparent R.A.	Apparent Dec.	Pos. Angle.	Dist.	Exp.	No. Plate.
1905. d h m	h m s	° ′ ″	° ′	′ ″	m s	
Aug. 23 13 30	4 10 42·567	+20 26 41·62	310 42·3	25 30·0	30 0	2028
23 14 23	4 10 43·162	+20 26 43·01	310 33·9	25 33·2	31 30	2029
Sept. 3 15 17	4 13 37·103	+20 32 25·60	291 12·1	36 54·4	40 0	2038
7 14 26	4 14 20·651	+20 32 56·45	286 34·2	40 48·4	60 0	2047
7 15 32	4 14 21·184	+20 32 56·78	286 32·0	40 49·8	55 0	2048

Date and G.M.T. 1905. d h m	Apparent R.A. h m s	Apparent Dec. ° ′ ″	Pos. Angle. ° ′	Dist. ′ ″	Exp. m s	No. Plate.
Sept. 8 12 56	4 14 29·561	+20 32 56·02	285 34·0	41 39·8	30 0	2050
12 14 37	4 15 1·576	+20 32 28·46	281 37·5	45 12·1	20 0	2054
12 15 5	4 15 1·639	+20 32 29·34	281 37·5	45 14·0	20 0	2055
12 15 42	4 15 1·783	+20 32 28·23	281 35·2	45 15·6	30 0	2056
30 12 17	4 15 14·100	+20 21 54·75	267 49·0	54 49·3	60 0	2068
Oct. 4 12 25	4 14 47·959	+20 17 52·93	265 0·7	55 25·7	40 0	2070
4 14 55	4 14 47·132	+20 17 45·73	264 55·8	55 26·3	34 0	2071
4 16 38	4 14 46·515	+20 17 40·98	264 52·7	55 27·4	39 0	2072
5 11 52	4 14 39·912	+20 16 48·24	264 18·7	55 30·6	30 0	2074
5 14 7	4 14 39·143	+20 16 42·09	264 14·8	55 30·5	59 14	2075
21 10 55	4 11 5·799	+19 55 34·19	251 59·5	51 52·5	45 0	2079
21 11 54	4 11 5·047	+19 55 30·30	251 57·4	51 51·8	45 0	2080
22 10 46	4 10 47·518	+19 54 2·67	251 6·4	51 23·2	40 0	2081
22 12 4	4 10 46·602	+19 53 57·18	251 2·4	51 20·2	75 0	2082
25 10 47	4 9 49·341	+19 49 17·99	248 14·7	49 43·1	30 0	2086
25 11 47 (*a*)	4 9 48·488	+19 49 15·10	248 13·3	49 41·2	60 0	2087
27 10 17	4 9 8·437	+19 46 5·39	246 14·0	48 30·5	40 0	2089
27 10 58	4 9 7·783	+19 46 3·27	246 12·2	48 29·5	28 51	
29 9 47	4 8 25·544	+19 42 49·58	244 7·0	47 13·8	30 0	2091
29 10 20	4 8 25·051	+19 42 47·72	244 5·4	47 11·8	25 0	2092
29 12 19*	4 8 23·396	+19 42 40·21	(243 59·9)	(47 6·6)	177 12	2093
29 14 17	4 8 21·417	+19 42 31·64	243 55·4	47 5·8	17 0	2094
31 10 24	4 7 39·848	+19 39 25·40	241 48·4	45 51·4	25 3	2096
31 10 49	4 7 39·427	+19 39 23·84	241 47·9	45 51·2	20 0	
31 12 3	4 7 38·347	+19 39 19·98	241 44·6	45 46·9	84 5	2097
Nov. 3 9 52	4 6 29·708	+19 34 22·57	238 5·4	43 42·9	30 0	2098
3 11 48	4 6 27·898	+19 34 12·33	237 57·8	43 37·7	54 17	2100
6 10 19	4 5 15·319	+19 29 7·67	233 53·3	41 27·0	15 0	2104
6 10 48	4 5 14·776	+19 29 5·29	233 51·7	41 26·7	15 0	2105
6 11 50	4 5 13·828	+19 29 0·56	233 46·0	41 23·4	70 0	2106
7 14 12	4 4 45·963	+19 27 5·83	232 7·0	40 33·8	15 0	2110
7 15 14	4 4 44·840	+19 27 1·23	232 3·1	40 32·2	90 0	2111
21 9 9	3 58 35·044	+19 3 4·29	203 32·5	31 34·7	15 0	2118
21 9 27	3 58 34·684	+19 3 3·42	203 31·1	31 34·0	15 0	
23 12 26	3 57 35·788	+18 59 28·13	197 46·7	30 45·6	90 0	2121

* Owing to the long exposure (nearly 3 hours) the star trails are so long that the results of the measures are liable to considerable uncertainty.

(*a*) Very poor image.

Date and G.M.T.		Apparent R.A.	Apparent Dec.	Pos. Angle.	Dist.	Exp.	No. Plate.
1905.	d h m	h m s	° ′ ″	° ′	′ ″	m s	
Nov.	23 13 33	3 57 34·454	+18 59 23·84	197 39·8	30 44·6	15 0	2122
	23 13 53	3 57 34·064	+18 59 22·12	197 37·6	30 44·3	20 0	
	24 10 31	3 57 10·277	+18 57 55·76	195 11·9	30 29·2	60 0	2126
	24 11 19	3 57 9·358	+18 57 52·72	195 6·2	30 28·3	10 0	2127
	24 11 33	3 57 9·069	+18 57 51·70	195 4·3	30 28·1	15 0	
	27 6 52 (*b*)	3 55 51·612	+18 53 16·58	187 1·1	29 55·8	5 0	2129
	27 7 1 (*b*)	3 55 51·502	+18 53 16·14	186 58·4	29 55·5	10 0	
	29 9 38	3 54 53·828	+18 49 54·97	180 47·2	29 50·0	20 0	2131
	29 9 55	3 54 53·525	+18 49 53·57	180 44·6	29 50·2	10 0	
	29 10 33	3 54 52·844	+18 49 51·23	180 39·1	29 50·1	30 0	2132
	29 11 17	3 54 52·062	+18 49 48·63	180 32·4	29 49·9	19 0	2133
Dec.	19 6 56	3 46 49·665	+18 24 32·09	134 28·0	39 34·1	60 0	2141
	19 7 50	3 46 48·978	+18 24 30·27	134 23·2	39 36·4	30 0	2142
	19 8 21 (*a*)	3 46 48·517	+18 24 29·85	134 20·6	39 36·7	7 30	2143
	19 8 34	3 46 48·372	+18 24 28·88	134 19·9	39 37·7	15 0	
	25 7 44	3 44 56·674	+18 19 47·59	126 15·5	44 6·9	18 30	2147
	25 8 41	3 44 56·088	+18 19 45·69	126 12·1	44 9·7	30 0	2149
	25 9 34	3 44 55·469	+18 19 44·42	126 9·3	44 11·4	60 0	2150
	25 10 21	3 44 54·884	+18 19 43·86	126 6·5	44 12·1	5 0	2151
	25 10 32	3 44 54·755	+18 19 43·14	126 6·5	44 12·6	15 0	
	30 7 42	3 43 39·272	+18 17 8·12	120 52·5	47 43·2	60 0	2153
	30 8 42	3 43 38·726	+18 17 6·89	120 50·0	47 45·3	25 45	2154
1906. Jan.	13 9 35	3 41 30·854	+18 16 26·58	109 54·9	55 46·8	30 0	2169
	13 10 11	3 41 30·715	+18 16 27·24	109 53·9	55 46·9	10 0	2170
	13 10 28	3 41 30·705	+18 16 27·45	109 53·4	55 47·7	10 0	2171
	15 12 11	3 41 23·599	+18 17 12·43	108 38·3	56 38·1	14 39	2174
	19 10 11 (*a*)	3 41 18·661	+18 19 14·80	106 24·4	57 57·6	90 0	2175
	19 11 15	3 41 18·739	+18 19 16·83	106 22·3	57 59·1	9 0	2176
	19 11 25 (*a*)	3 41 18·751	+18 19 17·35	106 21·9	57 59·3	8 0	
	22 9 4	3 41 22·465	+18 21 17·91	104 50·0	58 45·0	90 0	2180
	22 10 8	3 41 22·597	+18 21 21·21	104 47·3	58 45·6	10 0	2181
	22 10 19	3 41 22·604	+18 21 21·16	104 47·5	58 45·6	10 0	
	23 8 45	3 41 25·117	+18 22 5·99	104 18·6	58 57·3	60 0	2183
	23 9 47	3 41 25·307	+18 22 7·95	104 17·2	58 58·7	35 46	2184
	24 8 12 (*c*)	3 41 28·508	+18 22 55·00	103 49·2	59 9·3	60 0	2185
	26 10 12	3 41 37·892	+18 24 49·66	102 47·7	59 28·3	40 0	2186
	30 7 46	3 42 4·286	+18 28 58·90	100 55·1	59 52·1	30 0	2189

(*a*) Very poor image. (*b*) Very faint and diffused. (*c*) Faint.

Date and G.M.T.				Apparent R.A.			Apparent Dec.			Pos. Angle.		Dist.		Exp.		No. Plate.
1906.	d	h	m	h	m	s	°	′	″	°	′	′	″	m	s	
Jan.	30	8	30 (*d*)	3	42	4·388	+18	28	59·73	100	55·9	59	50·3	42	49	2190
	30	9	31	3	42	4·767	+18	29	3·69	100	53·6	59	50·9	10	44	2191
	30	9	45 (*e*)	3	42	4·847	+18	29	3·16	100	54·5	59	51·7	7	48	
Feb.	12	6	49 (*b*)	3	44	44·628	+18	47	25·81	95	23·0	57	51·6	35	0	2206
	12	7	30 (*c*)	3	44	45·067	+18	47	28·80	95	22·2	57	50·5	35	0	2207
	12	8	6	3	44	45·447	+18	47	31·53	95	21·4	57	49·5	15	0	2208
	12	8	18 (*f*)	3	44	45·581	+18	47	31·75	95	21·8	57	49·3	7	0	
	14	7	49	3	45	20·593	+18	50	59·30	94	28·0	57	18·9	25	40	2213
	15	8	24	3	45	39·672	+18	52	48·90	94	1·2	57	1·1	35	0	2217

(*b*) Very faint and diffused. (*c*) Faint. (*d*) Very diffused.
(*e*) Very faint. (*f*) Diffused.

Observations of Satellite VII.

Date and G.M.T.				Apparent R.A.			Apparent Dec.			Pos. Angle.		Dist.		Exp.		No. Plate.
1905.	d	h	m	h	m	s	°	′	″	°	′	′	″	m	s	
Oct.	22	12	4 (*a*)	4	11	21·917	+20	22	37·71	286	35·5	41	52·3	75	0	2082
	29	12	19 (*b*)	4	9	14·364	20	12	25·29	286	39·5	31	34·7	177	12	2093
	29	14	17	4	9	12·664	20	12	16·70	286	37·5	31	27·8	17	0	2094
	31	12	3	4	8	33·873	20	9	13·19	286	43·8	28	22·1	84	5	2097
Nov.	3	11	48 (*c*)	4	7	29·995	20	4	11·40	286	57·6	23	18·0	54	17	2100
	6	11	50 (*c*)	4	6	22·872	19	58	53·38	287	29·0	17	53·1	70	0	2106
	7	15	14	4	5	55·910	19	56	49·95	287	42·7	15	55·2	90	0	2111
	23	12	26 (*d*)	3	59	14·996	19	26	2·13	100	58·6	14	17·0	90	0	2121
	24	10	31	3	58	50·433	19	24	13·13	101	17·1	15	57·3	60	0	2126
	29	10	33	3	56	37·172	19	14	21·63	102	18·1	24	51·4	30	0	2132
Dec.	19	6	56 (*c*)	3	48	11·497	18	40	40·88	103	35·3	48	56·8	60	0	2141
	25	8	41	3	45	56·035	18	33	19·26	104	3·1	51	20·2	30	0	2149
	25	9	34	3	45	55·293	18	33	18·07	104	2·0	51	20·9	60	0	2150
	30	7	42 (*e*)	3	44	16·984	18	28	44·11	104	27·1	51	29·2	60	0	2153
	30	8	42	3	44	16·128	18	28	42·34	104	27·4	51	27·7	25	45	2154
1906. Jan.	19	10	11 (*e*)	3	40	0·128	18	24	18·82	107	8·0	38	39·6	90	0	2175
	23	8	45 (*f*)	3	39	42·537	18	26	9·57	107	57·1	34	27·1	60	0	2183
	23	9	47 (*g*)	3	39	42·536	18	26	10·59	107	57·4	34	26·1	36	46	2184
	26	10	12	3	39	37·292	18	28	9·57	108	43·7	31	1·3	40	0	2186

(*a*) Very diffused.
(*b*) Very diffused. Star trails 66″ long, and consequently subject to uncertainty in measurement of their positions.
(*c*) Very faint. (*d*) Faint and diffused. (*e*) Very poor photograph.
(*f*) Extremely faint. (*g*) Faint.

Royal Observatory, Greenwich:
1906 *May* 11.

Observations of Uranus at Windsor, New South Wales. By John Tebbutt.

The following are the results of comparisons of *Uranus* made with *I Sagittarii* by means of the filar micrometer on the 8-inch equatorial. The estimated centre of the planet's disc was chosen for observation. The last two columns contain a comparison of the results with the transit ephemeris on page 280 of the *Nautical Almanac*.

1905.	Windsor Mean Time.	Planet—Star		No. of Comps.	Reduction to Apparent Place.		Parallax Corrections.		Concluded Geocentric Apparent Place of Planet.		Obs.—Cal.	
		Δα.	Δδ.		α.	δ.	α.	δ.	α.	δ.	α.	δ.
	h m s	s	″		s	″	s	″	h m s	° ′ ″	s	″
July 15	8 47 29	+14·34	+47·2	10	+2·81	+8·9	−0·01	−0·1	18 6 12·61	−23 42 20·1	+0·11	−2·0
„ 16	8 45 45	+ 4·56	+45·2	6	+2·81	+8·9	−0·01	−0·1	18 6 2·83	−23 42 22·1	−0·02	−2·3
„ 17	8 13 37	− 4·72	+44·4	20	+2·81	+8·9	−0·02	−0·1	18 5 53·54	−23 42 22·9	+0·05	−1·5
„ 21	7 41 38	−41·78	+38·3	20	+2·81	+8·8	−0·02	−0·1	18 5 16·48	−23 42 29·1	+0·07	−2·0
„ 22	7 40 34	−50·86	+37·3	20	+2·81	+8·8	−0·02	−0·1	18 5 7·40	−23 42 30·1	+0·04	−1·7
„ 23	7 40 57	−59·90	+36·2	20	+2·81	+8·8	−0·02	−0·1	18 4 58·36	−23 42 31·2	−0·05	−1·5

The mean place of the comparison star for 1905·0 is $\alpha = 18^h\ 5^m\ 55^s{\cdot}47$, $\delta = 23°\ 43'\ 16''{\cdot}1$. It is derived from the following authorities: Argentine Gen. Cat. 1875, No. 24755; Greenwich Ten-year Cat. 1880, No. 2884; Stone, 1880, No. 9907; Greenwich 2nd Ten-year Cat. 1890, No. 4509; and Radcliffe Cat. 1890, No. 4748.

Observatory, Peninsula, Windsor, N.S. Wales:
1906 *March* 8.

Observations of Comet c 1905 made at the Natal Observatory, Durban.

(Communicated by E. Nevill.)

The following observations were made by Mr. Rendell by means of a cross-bar micrometer with the equatorial refractor, aperture 8 inches, focal length 10 feet, magnifying power 50.

Date. 1906.	Greenwich Mean Time. h m s	Apparent Difference Comet—Star. R.A. m s	Apparent Difference Comet—Star. N.P.D. ′ ″	Comet's Approx. Hour-angle. h m	No. of Comparisons.	Comparison Star.
Feb. 16	6 7 7	−0 46·83	−3 22·8	5 20 W	6	*a*
18	6 4 47	+1 22·02	+0 56·2	5 13 W	4	*b*
20	6 16 6	+1 33·31	−3 21·1	5 19 W	6	*c*
21	5 57 5	−1 1·14	−3 3·1	4 58 W	6	*d*
22	5 51 24	−0 11·24	−1 2·7	4 50 W	6	*e*
25	5 45 8	+0 24·64	−4 2·9	4 39 W	4	*f*

Comparison Stars.

		R.A. h m s	N.P.D. ° ′	
a	B.D. −15° No. 119	0 32 34·8	105 31·8	(1855·0)
b	B.D. −13° No. 142	0 44 0·9	103 54·3	"
c	B.D. −12° No. 196	0 56 33·3	102 26·8	"
d	B.D. −11° No. 224	1 5 1·9	101 42·8	"
e	B.D. −10° No. 270	1 9 59·9	100 57·3	"
f	B.D. − 8° No. 265	1 25 37·0	98 54·0	"

[Star *b* = Lalande 1422 = Paris 1074; star *d* = Lalande 2164 = Paris 1542.]

Notes.

The observations were taken each evening as soon as possible after sunset.

The comet, although rather low in the sky, and somewhat faint, was visible on each occasion in the 3-inch finder. No stellar nucleus was seen.

The nebulosity, in diameter about 1′, was fairly dense.

Faint extensions could not be detected.

On February 20 the comet appeared to be growing fainter and a little more diffused.

Estimated to be almost as faint as B.D. −12° No. 202 (mag. 10).

On February 21 it was estimated to be a little brighter than B.D. −11° No. 221 (mag. 9·7).

The observations have not been corrected for refraction or parallax.

Natal Observatory, Durban:
1906 *March* 23.

Note on the Parallax and Proper Motion of the Central Star in the Annular Nebula in Lyra. By Burt L. Newkirk.

(Communicated by Professor A. O. Leuschner.)

In a recent article on the annular nebula in *Lyra* (*Monthly Notices,* vol. xlvi., page 106) Professor Barnard draws the following conclusion concerning my investigation of the parallax of the central star: "As Dr. Newkirk's parallax for the central star depends upon the proper motion which he determined, and which is shown not to exist, the parallax itself must be fallacious."

This conclusion is not justified unless a solution of the equations of condition with the proper motion terms omitted indicates that no measurable parallax exists. I have made such a solution with the following results from the eight pairs of comparison stars:—

Pair	π.
	$''$
1– 2	0·00
3– 4	+0·17
5– 6	+0·07
7– 8	+0·02
9–10	+0·13
11–12	+0·06
13–14	+0·05
15–16	+0·07

Weighted mean parallax = $+0·067 \pm 0''·02$ mean error.

The result obtained when proper motion terms are included in the equations of condition is

$$\pi = +0''·10 \pm 0·02 \text{ M.E.}$$

If instead of averaging these eight values equations of condition be set up for the simultaneous determination of the parallax and the effect of chromatic dispersion, the above value of the parallax is reduced by $0''·003$ only.

I am fully aware of the uncertainty which attaches itself to investigations of stellar parallax, and realise the desirability of a thorough test of my results. An investigation of proper motion alone, however, does not seem likely to throw much light on the value of the parallax.

Most of the plates used in my parallax investigation were exposed during the years 1899 and 1900, and the series could not therefore form a good basis for an investigation of proper motion. This is explicitly stated on page 15.

The proper motion obtained from the photographic measures was:

$$\Delta\alpha = -0^{s}{\cdot}01 \pm 0^{s}{\cdot}0036$$
$$\Delta\delta = -0''{\cdot}00 \pm 0''{\cdot}045$$

A comparison of measures of the distance nucleus to star *a*, made at various times by Burnham, Scheiner, Barnard, and Leavenworth gives the values:

$$\Delta\alpha = +0^{s}{\cdot}01 \pm 0^{s}{\cdot}0013\ *$$
$$\Delta\delta = +0''{\cdot}18 \pm 0''{\cdot}037$$

The weighted mean is, in the case of $\Delta\alpha$, practically independent of my photographic measures.

The evidence of proper motion which was presented as a supplement to the parallax investigation rested, therefore, mainly on observational material not used in the parallax determination.

Students' Observatory, University of California, U.S.A.:
1906 *March* 6.

Some Considerations regarding the Number of the Stars. By Winifred Gibson, B.Sc., Jessel Student, University College, London.

(*Communicated by Professor Karl Pearson, F.R.S.*)

(1) The aim of the following investigation is to consider whether any suggestion of a limitation of the number of the stars can be inferred from the very full statistics we already possess with regard to stars of the lower magnitudes.

If the universe be at all comparable with the atomic congregations such as we find the physicist postulating in the kinetic theory of gases, we might not unreasonably assume that some one or more characteristics of the stars may obey a chance law of distribution in their frequency; and hence, if we knew fairly well the frequency distribution for stars of the lower magnitudes, we might hope to construct somewhat roughly the total frequency distribution, and thus possibly obtain a measure, if only the crudest, of the total number of stars.

Unfortunately, however, there is only one character of the stars of which we have as yet anything like ample enough statistics for an inquiry of this kind, namely, the frequency of stars up to about the tenth magnitude; and even on this point star catalogues and authors are far from being in complete agreement. Proper motions, parallaxes, colours, spectroscopic measurements, &c. have been ascertained at present for too

* By an unfortunate error this was given the negative sign, thus seeming to agree with the results of the photographic measures.

few stars to render it at all hopeful to consider frequency distributions for such characters, and even such determinations of these properties as have already been made are far too doubtful and unreliable to form the basis of accurate statistical reasoning.

We are therefore thrown back on magnitude as the only character for which at present a frequency distribution is practicable. But it is impossible to consider magnitude as a quantity which in nature itself could be the basis of a chance distribution of frequency. It is largely physiological, and is influenced by a variety of causes which it is difficult to disentangle, and of which one or more might be the basis of a real chance distribution. Thus the frequency of the stellar distances from the Sun or from any other point in the universe might conceivably follow a chance distribution; the size of the stars might do so; their colour or the intensity of their lights; but it is hardly conceivable that a scale of pure magnitude could have any meaning in physical nature. If, however, we could obtain a scale in which successive magnitudes should correspond to equal increases in the amount of light, we might possibly obtain a chance distribution of frequency.

Starting from Fechner's Law of Sensation, that the increment of sensation is proportional to the relative increase of the excitation, we should have

$$\delta S \propto \delta l / l$$

where S is the sensation of light, which is really what we are measuring with magnitude, and l is a physical measure of the intensity of light.

It follows from this that if m_1 and m_2 be two magnitudes corresponding to physical amounts l_1 and l_2 of light,

$$m_2 - m_1 = C(\log l_1 - \log l_2)$$

where C is a constant, or

$$l \propto C'/a^m \quad \ldots \quad \ldots \quad \ldots \quad \text{(i.)}$$

The validity of this reasoning as well as Fechner's Law itself may well be called in question, and it is enough merely to define the relation of magnitude to amount of light by (i.), where astronomers are agreed to give to a Pogson's value 2·51189, so that $\log_{10} a = \cdot 4$. Now the magnitudes as determined by the amounts of light received by (i.) may give a chance distribution when their frequencies are simply plotted to this light, or it may be needful to replace light by some other character of which it is a function, such as the inverse square of the distance d from the Earth. In the latter case we have

$$\begin{aligned} m_1 - m_2 &= \frac{2}{\log a}(\log d_1 - \log d_2) \\ &= 5(\log d_1 - \log d_2) \quad \ldots \quad \ldots \quad \text{(ii.)} \end{aligned}$$

According to this there would be an invariable relation between magnitude and distance which should manifest itself in a very high correlation between the two characters magnitude and parallax.

Again, if stars were scattered at random throughout space, we should have the number n inside a sphere of radius d proportional to d^3, or

$$m_1 - m_2 = \tfrac{5}{3}(\log n_1 - \log n_2) \quad \ldots \quad \ldots \quad \text{(iii.)}$$

But the accuracy of (iii.) would, unless a corrective combination of errors were called into play, be no greater than that involved in the hypothesis that the relative light of the stars is due wholly to their distances.

(2) So far we have been dealing purely with somewhat vague hypotheses—Fechner's Law, the variation of stellar light with the square of the distance, which neglects the absolute intensity of light of individual stars, and the random scattering of stars in space. A necessary fundamental step seemed to be the testing of such matters by the modern methods of statistics. Unfortunately the amount of material at our disposal is comparatively small. Newcomb, in his book on the Stars,* gives the parallax of 72 stars, and this is the longest list I have been able to find. A considerable number of these stars are noted as being of rather doubtful parallax; still this material is all we have at present to justify what appear otherwise to be rather sweeping conclusions.

The first step taken was the investigation of the correlation of parallax and magnitude of stars. As noted before, if the magnitude of stars is closely related to their distance, we should expect this correlation to be a high one.

Table I. is the resulting correlation table. In this table the column $0''\cdot30$, say, contains all stars with a parallax equal to or greater than $0''\cdot30$ and less than $0''\cdot35$; that is, since the stars' parallaxes are tabled to two decimal places only—all stars between $0''\cdot295$ and $0''\cdot345$—the row 3, say, contains all stars of magnitude 3 to 3·5. The statistical constants of this table were obtained in the usual manner *on the assumption that magnitude is a uniformly graded variable.* There resulted:

Mean parallax $= 0''\cdot145 \pm 0''\cdot011$

Standard deviation in parallax $= 0''\cdot134 \pm 0''\cdot007$

Mean magnitude $= 4\cdot026 \pm \cdot218$

Standard deviation in magnitude $= 2\cdot741 \pm \cdot154$

Correlation between parallax and magnitude $= \cdot103 \pm \cdot079$

This somewhat astonishing result indicates that a star of low magnitude, *i.e.* a bright star, is on the average associated with a low parallax, *i.e.* a great distance. The probable error of the result indicates, however, that for the stars dealt with *there is no*

* *The Stars: a Study of the Universe.* Murray, 1902.

sensible relation between magnitude and parallax. In other words, assuming we may treat magnitude as a uniformly graded variable, we are compelled to conclude that on the results available, which do not go beyond stars of the ninth magnitude, there is no evidence whatever that magnitude is in any way associated with distance. The bearing of this result on differential methods of ascertaining parallax, if brightness and not proper motion be taken as a test of relative distance, is considerable.

TABLE I.

Correlation of Parallax and Stellar Magnitude.

Value of Magnitude.	Value of Parallax.																Totals.
	″·00.	″·05.	″·10.	″·15.	″·20.	″·25.	″·30.	″·35.	″·40.	″·45.	″·50.	″·55.	″·60.	″·65.	″·70.	″·75	
−1·5	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	1
−1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
− ·5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0
0	2	1	1	...	...	...	...	...	...	...	...	...	...	...	...	1	5
·5	2	1	...	...	1	...	1	...	...	...	...	...	...	...	...	...	5
1	3	1	2	...	...	...	...	...	...	...	...	...	...	...	...	...	6
1·5	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	2
2	2	2	...	1	...	...	...	...	...	...	...	...	...	...	...	...	5
2·5	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	2
3	...	2	2	...	...	...	...	...	...	...	...	...	...	...	...	...	4
3·5	...	...	...	...	1	...	1	...	1	...	...	...	...	...	...	...	3
4	1	...	2	1	1	...	...	...	...	...	...	...	...	...	...	...	5
4·5	...	1	...	1	1	1	1	1	...	...	...	...	...	...	...	...	6
5	1	1	2	...	...	...	...	...	...	...	...	...	...	...	...	...	4
5·5	1	2	...	1	...	...	...	...	...	...	...	...	...	...	...	...	4
6	2	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	3
6·5	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...	2
7	...	1	...	1	...	1	...	...	...	...	...	...	...	...	...	...	3
7·5	1	1	...	...	1	...	...	...	...	1	...	...	...	...	...	...	4
8	1	1	...	1	...	...	1	...	...	...	...	...	...	...	...	...	4
8·5	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	2
9	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	1
Totals	18	15	12	7	7	3	4	3	1	1	...	...	...	...	...	1	72

The question then naturally arose as to whether the fault lies with parallax or magnitude. To test this the correlations between parallax and (*a*) proper motion in R.A., and (*b*) proper motion in declination, were obtained for the same 72 stars.

I have most heartily to thank Dr. A. Lee for working out

these values: they were obtained *without grouping* from the second moments and product moments of the whole material. The results were as follows:—

Mean parallax $= 0''\cdot141 \pm 0''\cdot011$*

Standard deviation of parallax $= 0''\cdot132 \pm 0''\cdot007$

Mean proper motion R.A. $= 0^{s}\cdot106 \pm {}^{s}\cdot012$

Standard deviation of proper motion R.A. $= 0^{s}\cdot154 \pm {}^{s}\cdot009$

Mean proper motion declination $= 0''\cdot657 \pm ''\cdot070$

Standard deviation of proper motion in declination $= 0''\cdot878 \pm ''\cdot049$

Correlations:—

Parallax and proper motion in R.A. $= \cdot435 \pm \cdot064$

Parallax and proper motion in declination $= \cdot414 \pm \cdot066$

Proper motion in R.A. with proper motion in declination $= \cdot293 \pm \cdot073$

Now these results are distinctly lower than we might have anticipated. We might expect *à priori* a very high association between parallax and proper motion; the results show it to be quite significant and important, but not halfway up the scale of correlation. This, perhaps, may confirm the view that many parallaxes are unreliable; but it may also serve to show that some extremely distant stars have very large proper motions.

Before we leave this point it is worth putting on record the most probable value of the parallax of a star whose proper motions in right ascension and declination have been measured. It was found in the usual manner and is given by the equation below. $\Pi =$ probable parallax in seconds of angle; $p_{AR} =$ proper motion in R.A. in seconds of time, $p_{\delta} =$ proper motion in declination in seconds of arc. The formula is then

$$\Pi = ''\cdot079 + ''\cdot294 p_{AR} + ''\cdot047 p_{\delta} \pm ''\cdot076 \qquad \ldots \quad \text{(iv.)}$$

In using this formula no attention, of course, must be paid to the *sign* of the proper motions.

Now any determination of parallax will only differ from the mean value $0''\cdot141$ with a probable error of $0''\cdot089$. Thus by predicting parallax from proper motion we only reduce the probable error of the estimate $0''\cdot089$ to $0''\cdot076$, no very great improvement. We therefore conclude that the knowledge of the proper motion of a star in right ascension and declination does not enable us to form any good estimate of what its parallax is likely to be.

* Allowing for the effect of grouping, these results for parallax are in agreement with those given above.

The following table illustrates the point :—

Table of Observed and Estimated Parallaxes.

Star.	Observed Parallax.	Estimated Parallax.	Star.	Observed Parallax.	Estimated Parallax.
α Centauri	0''·75	0''·256	Formalhaut	0''·13	0''·141
Sirius	·37	·142	Aldebaran	·11	·090
γ' Draconis	·32	·092	Capella	·09	·102
Procyon	·30	·147	Pollux	·06	·096
β Cassiopeiæ	·15	·108			

It was not, of course, possible to let the question of magnitude and distance rest at the point indicated above. Magnitude is a physiologically and not a physically graded variate, *i.e.* a unit of magnitude high in the scale is not physically equal to one low in the scale. On this account it seemed advisable to reinvestigate the whole matter, in this case taking light units as given by equation (i.), with Pogson's value for a, and correlating once more with parallax.

The light of a star of the tenth magnitude was taken as the unit of light, or we have

$$l = \frac{10000}{(2\cdot51189)^m} \quad \dots \quad \dots \quad \dots \quad \text{(v.)}$$

The vertical coordinate was now taken to be l instead of m, and the correlation again worked out. From this we have :

Mean parallax $= 0''\cdot145 \pm ''\cdot011$

Standard deviation in parallax $= 0''\cdot134 \pm ''\cdot008$

Mean amount of light $= 2669\cdot21 \pm 470\cdot66$ units

Standard deviation in light $= 5921 \pm 332\cdot82$ units

Correlation between light and parallax $= \cdot094 \pm \cdot079$

This gives a positive correlation—which is insensible having regard to its probable error—between intensity of light and magnitude of parallax. The star *a Centauri*, which has the exceptionally large parallax of 0''·75, was obviously very influential on this result. On this account, although this is a well-determined parallax, it seemed worth while recalculating the correlation, omitting *a Centauri* from the table. The correlation was then found to be ·029 ± ·079, which is absolutely insensible. Thus ⅔ of the slight correlation already noticed is only due to the excessive parallax of this single very bright star.

We have thus found that, while the paradox of "less light greater nearness" disappears when we change our physiological into physical units of luminosity, we are still left with the same general conclusion that the parallaxes already determined give no sensible relation between intensity of light and stellar distance.

It appeared in the next place worth while considering whether the result obtained may be due to absence of linear regression. In non-technical language can it possibly be that there is a fairly close relation between light and distance, but that distance does not on the average decrease proportionately to the increase of light received? There might exist, for example, a curved regression line, giving a low coefficient of correlation, a large class of bright stars being at a great distance, or a similar class of faint stars being in our more immediate neighbourhood.

To test this we must proceed either by the method of contingency * or the use of the correlation ratio.†

Accordingly the observations were clubbed together in Table II. Alongside the number of stars falling into each group is given the number which might be expected to appear, if the relation between parallax and magnitude were purely random in its character, *i.e.* on the theory of independent probability.

From these results the coefficient of mean square contingency was calculated in the usual manner. This coefficient must lie between 0 and 1, and if the distribution were Gaussian, involving linear regression, it should be closely equal to the coefficient of correlation.

Its value was found to be ·408. This is a most sensible rise on the value ·094 previously determined for the correlation.

TABLE II.

Contingency Table between Parallax and Stellar Magnitude.

	Parallax.	″·00 to ″·05.	″·05 to ″·15.	″·15 to ″·25.	″·25 to ″·30.	″·30 and over.	Totals.
Magnitude.	−1·5 to 1	8·5 (4·75)	3 (3·96)	3 (5·01)	1·5 (2·64)	·3 (2·64)	19
	1 „ 3	2·5 (3·375)	5 (2·81)	4 (3·56)	1 (1·875)	1 (1·875)	13·5
	3 „ 5	2·5 (4·625)	3 (3·85)	6·5 (4·88)	3·5 (2·57)	3 (2·57)	18·5
	5 „ 7	3 (3·00)	2·5(2·50)	4·5 (3·17)	1·5 (1·67)	·5 (1·67)	12
	7 „ 9	1·5 (2·25)	1·5(1·875)	1 (2·375)	2·5 (1·25)	2·5 (1·25)	9
	Totals ...	18	15	19	10	10	72

In forming this contingency table the dimensions were selected to give fairly uniform groups—the actual units of classification having, of course, no influence on the result, which is simply a measure of the deviations of the numbers to be expected in each group on the theory of absolute independence of the variates from the actually observed numbers.

This great increase in the association between luminosity and parallax seemed to demand some explanation, and accordingly the correlation-ratio usually represented by η was calculated.

* Pearson, "On the Theory of Contingency and its Relation to Association and Normal Correlation," *Drapers' Company Research Memoirs*, i. 1904.

† Pearson, "On the General Theory of Skew Correlation and Non-linear Regression," *Drapers' Company Research Memoirs*, ii. 1905. Dulau & Co.

If η be equal to the correlation coefficient r, the regression is linear; if it be sensibly different from r, then the correlation is non-Gaussian and sensibly skew. The means of the arrays of parallax corresponding to the five groups of luminosity in Table II. were then determined, and from these means the correlation ratio η was found in the usual way: its value was ·486. It thus amply confirms the result obtained from the coefficient of contingency. The values of both are five to six times their probable errors, and the difference between η^2 and r^2 is three to four times its probable error. We must conclude therefore that there exists:—

(i.) A significant association between distance and luminosity.

(ii.) This association is not, however, one in which, on the average, increase of distance is proportional to decrease of luminosity.

The question naturally now arises as to whether the relationship is one which could be expressed by any smooth mathematical function. Unfortunately seventy-two stars are far too few to determine a relationship of such a nature. It is, however, worth while looking at a graph of the mean parallax corresponding to each magnitude. Examining fig. 1 we see that on the present data nothing better than a horizontal straight line* at the mean parallax, or a zero correlation coefficient is likely to be found to fit the observations.

But the values of the contingency and correlation ratio indicate that the deviations from this straight line, however hopelessly irregular they appear, are not within the limits of random-sampling. The material is far too sparse to draw dogmatic conclusions from, but it pointedly suggests: (*a*) that while there appears to be no continuous relation between luminosity and distance, certainly no average proportionality between changes in the two, yet (*b*) there is some significant discontinuous relation between the two variates which removes them from the field of independent characters. For example, stars of a definite range of magnitude may be at a certain average distance, but there may be no uniform arrangement of clusters of stars of given magnitude in order of distance.†

It will be clear, therefore, that distance as rigidly related to magnitude by any such relation as (ii.) (p. 446) is not a stellar character upon which we can start with any idea of a random chance distribution. So far as any evidence is at present forthcoming, we cannot replace the magnitude variate by a corre-

* It is possible that a curve of a somewhat complex character—a quartic curve, for instance—might fit the observations.

† The conception can be illustrated by the march past of troops at a review; the men in the various regiments would have degrees of efficiency depending on their regimental commanders. Thus in the line of march past the saluting-point efficiency would be contingent on distance; but if the troops were drawn up in this line with a random distribution of regiments, there would be no continuous relation between efficiency and distance, *i.e.* the coefficient of correlation would be zero.

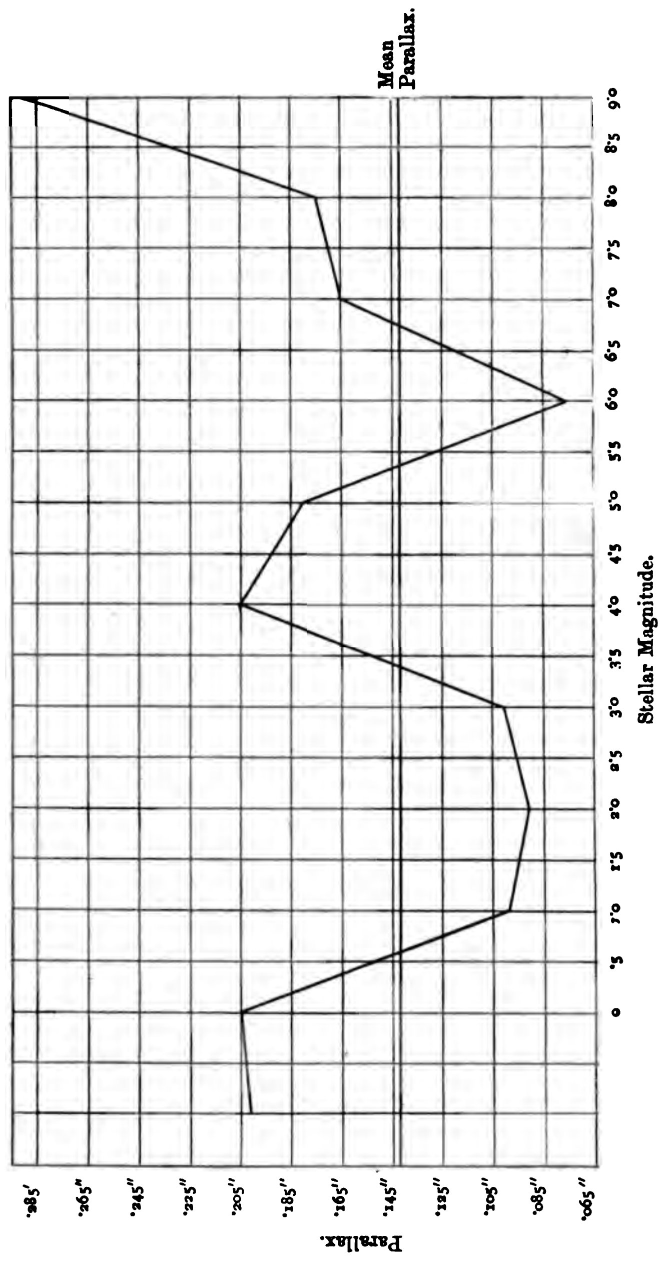


FIG. 1.—Parallax and Stella Magnitude.

sponding distance. It is needless to say that the suggestion of a non-graduated discontinuous relation between luminosity and distance can only be verified or disproved when far more parallax data are available.

(3) The next stage in the work was to inquire whether magnitude was more markedly correlated with any other character than parallax. Colour suggested itself as a character for which definite data were available.

In vol. ix. of the *Annals of the Cape Observatory* will be found a catalogue from which the colour of 159 stars can be extracted. The following colour classification is used at the Cape :—

0 White.	6 Orange red.
1 Yellowish.	7 Reddish.
2 Yellow.	8 Red.
3 Deep yellow.	9 Very red.
4 Orange yellow.	10 Deepest red.
5 Orange.	

For the purpose of forming a contingency table from comparatively scanty data, 1, 2, and 3 were thrown together as *yellow* ; 4, 5, 6, and 7 were still retained as independent groups ; and 8 and 9 thrown together as *red* ; 0 and 10 had no frequency in the record.

Table III. gives the correlation table for *visual* magnitude, Table IV. throws it into the form of a contingency table, and Table V. is a contingency table for photographic magnitudes.

TABLE III.

Association of Colour and Visual Magnitude.

Magnitude.

Cape Colour Scale.	4	4·5	5	5·5	6	6·5	7	7·5	8	8·5	9	9·5	Totals.
1	...	...	...	1	...	...	...	...	...	...	...	...	1
2	...	...	...	...	...	1	1	1	...	...	...	...	3
3	...	...	...	...	...	...	·5	1	2	...	3	...	6·5
4	...	...	...	3	2	2	2·5	2	7	2	4	...	24·5
5	...	...	1	1	1	...	5·5	6	4	6	4	2	30·5
6	·5	...	2	1	3	3·5	6	4·5	8	10·5	8	...	47
7	·5	...	...	1·5	·5	2	1	3·5	3	9·5	6	...	27·5
8	...	...	1	·5	1	1·5	1·5	1·5	1·5	·5	3	1·5	13·5
9	...	...	...	..	·5	...	...	1·5	·5	·5	1	1·5	5·5
Totals	1	0	4	8	8	10	18	21	26	29	29	5	159

TABLE IV.

Contingency Table of Colour and Visual Magnitude.

Magnitude.

Colour Scale.	4	5	6	7	8	9	Totals.
Yellow	0	1	1	3·5	2	3	10·5
Orange Yellow	0	3	4	4·5	9	4	24·5
Orange	0	2	1	11·5	10	6	30·5
Orange Red	·5	3	6·5	10·5	18·5	8	47
Reddish	·5	1·5	2·5	4·5	12·5	6	27·5
Red	0	1·5	3	4·5	3	7	19
Totals ...	1	12	18	39	55	34	159

TABLE V.

Contingency Table of Colour and Photographic Magnitude.

Magnitude.

Colour Scale.	6	7	8	9	10	Totals.
Yellow	1	1·5	4	3	1	10·5
Orange yellow	1	5·5	7·5	10·5	...	24·5
Orange	...	4·25	11·25	12	2	29·5
Orange red	·5	7·25	17·25	19·25	2·75	47
Reddish	·5	2·75	5·75	11·75	4·75	25·5
Red	...	2·75	2·75	7·5	1	14
Totals	3	24	48·5	64	11·5	151

The results given by these contingency tables are as follows:

Mean visual magnitude ... ... = $7·72 \pm ·063$

Standard deviation of visual magnitude ... = $1·174 \pm ·044$

Coefficient of contingency between colour and visual magnitude ... ... = ·298

Mean photographic magnitude ... ... = $8·58 \pm ·046$

Standard deviation of photographic magnitude = $·835 \pm ·032$

Coefficient of contingency between colour and photographic magnitude ... ... = ·304

This amount of agreement is extremely satisfactory considering the very considerable difference in the distribution of magnitudes in the two cases. As we possess no quantitative colour scale it is impossible to compare these results with those obtained from straightforward correlation calculations, but it

seems worth while to examine the mean visual magnitude corresponding to each colour group.

Mean magnitude for all colours		... ...	= 7·92
,,	,,	Yellow stars	= 7·87
,,	,,	Orange yellow stars	= 7·67
,,	,,	Orange stars	= 8·00
,,	,,	Orange red stars	= 7·84
,,	,,	Reddish stars	= 8·14
,,	,,	Red stars	= 8·02

These results, while still very irregular, do show (fig. 2) a general tendency to higher magnitude as we pass from the yellow to the red stars; but it must be remembered that the absence of any quantitative colour scale only allows of a very rough *graphical* appreciation of the relationship.

We see, however, that while the contingency coefficient of magnitude on colour is somewhat less than in the case of magnitude and parallax, there yet appears to be a possibility of a more continuous and graduated relationship in the former case than in the latter. To sum up, then, we find that there is no well-marked and very definite relationship between magnitude and either parallax or colour. Such association as appears to exist from the data at present available seems, however, to point to *quality* of light rather than distance as having a continuous and proportional effect on magnitude.

(4) From what precedes it will be clear that, frequencies being given in terms of magnitude, there is small hope of our being able to approach stellar frequency from the standpoint of a chance distribution, the variate being either distance or colour, the correlations between these and magnitude being far too small to allow of any replacement of magnitude by these variates. If any formula like (iii.) be taken it will be found to give far too high frequencies for stars of the fourth and higher magnitudes.

The only variate which appeared to present itself as a character which might possibly have a chance distribution was the amount of light as determined by equation (i.), p. 446.

We have seen that the amount of light is not closely associated with distance; it is therefore *à priori* conceivable that it is a character of the individual star which, like stature or head-measurements in a population of men, is closely described by a chance distribution of frequency. The main difference would be that in the case of the anthropometric measurements we are able to observe the whole frequency distribution of a random sample, while in the case of the stars we can only observe the frequency of the tail of the distribution—*i.e.* the frequency of those stars whose luminosity is sufficiently great to allow of a count.*

* A somewhat similar case of a knowledge of the "tail" only arises in the case of speed of trotting horses, the record only including the fastest trotters. See *Biometrika*, vol. ii. pp. 2–6.

Accordingly, the first stage of the second part of the inquiry was to investigate whether the counts of stars up to the sixth magnitude could possibly be represented by the tail of a chance

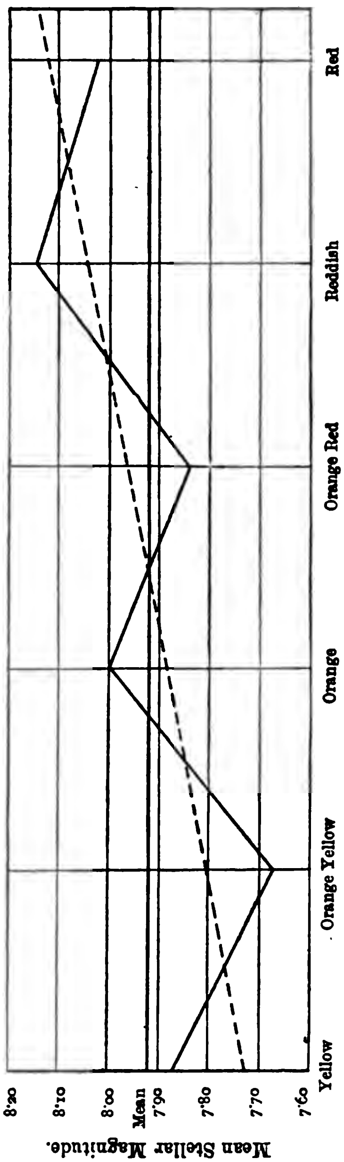


FIG. 2.—Relation between Stellar Magnitude and Colour

frequency curve, beginning in the first place with the ordinary Gaussian or normal curve.

Taking as unit of light the light of a star of the tenth magnitude, the amounts of light corresponding to stars ·75, 1·25, 1·75, 2·25 . . . &c., magnitudes were calculated from (i.). Then if n_1, $n_{1\cdot5}$, n_2, $n_{2\cdot5}$, &c., be the number of stars found from the counts between magnitudes ·75 and 1·25, 1·25 and 1·75, 1·75 and 2·25, 2·25 and 2·75, &c., the corresponding ordinates of the frequency distribution were taken as y_1, $y_{1\cdot5}$, y_2, $y_{2\cdot5}$, &c., where

$$\begin{aligned} y_1\ (x_{0\cdot75}-x_{1\cdot25}) &= n_1 \\ y_{1\cdot5}(x_{1\cdot25}-x_{1\cdot75}) &= n_{1\cdot5} \\ y_2\ (x_{1\cdot75}-x_{2\cdot25}) &= n_2 \\ y_{2\cdot5}(x_{2\cdot25}-x_{2\cdot75}) &= n_{2\cdot5}\ \text{\&c.} \end{aligned}$$

the abscissæ being taken as $\frac{1}{2}(x_{0\cdot75}+x_{1\cdot25})$, $\frac{1}{2}(x_{1\cdot25}+x_{1\cdot75})$, $\frac{1}{2}(x_{1\cdot75}+x_{2\cdot25})$, $\frac{1}{2}(x_{2\cdot25}+x_{2\cdot75})$, &c., where x_m represents the amount of light corresponding to magnitude m. Eight values were selected to work upon, namely, y_2, $y_{2\cdot5}$, y_3, $y_{3\cdot5}$, y_4, $y_{4\cdot5}$, y_5, $y_{5\cdot5}$, as being values corresponding to closely known star counts. When this work was begun Pickering's recent paper had not been published, and accordingly Newcomb's values of the counts were used.* These give :—

TABLE VI.

Magnitude.	Frequency.	Ordinate y.	Abscissa x.
2·0	32	·043458	1627·0950
2·5	41	·088248	1026·6290
3·0	78	·266084	647·7575
3·5	135	·730285	408·7075
4·0	240	2·056527	257·8770
4·5	462	6·274310	162·7095
5·0	876	18·855010	102·6630
5·5	1468	50·098461	64·7760

A curve of the form $Y = A + Bx + Cx^2$, where $Y = \log y$ was fitted by the method of least squares to the above eight points. The resulting equation was

$$Y = 1\cdot66915715 - \cdot00469533x + \cdot00000177x^2$$

If we throw this into the form of a Gaussian or normal curve

$$y = y_0 e^{-\lambda(x-h)^2} \qquad \dots \quad \dots \quad \dots \quad \dots \quad \text{(vi.)}$$

we find

$$\left.\begin{aligned} \lambda &= -\cdot00000408,\ h = 1326\cdot36525 \\ y_0 &= \cdot03592 \end{aligned}\right\} \qquad \dots \quad \text{(vii.)}$$

* *The Stars*, p. 53.

Since λ is negative, the index of e in (vi.) is positive, and the values of y will increase with those of x, whether x be positive or negative, from the point at which $x = h$. We see, therefore, that the standard deviation is imaginary, and the Gaussian curve has become a U-shaped curve with a minimum frequency at 1326 light units—*i.e.* between magnitudes 2 and 2·5, and with a frequency rising towards infinity as we approach zero amounts of light. Clearly the portion of the curve for amounts of light greater than correspond to magnitude 2 is quite meaningless. Further the fit between magnitudes 3·5 and 5·5 is a very poor one—it is hardly necessary to give the calculated ordinates. Accordingly we must conclude that *the distribution of light intensities of the stars has not the least approximation to the tail of a chance distribution of the Gaussian type.*

The curve given by y and x in Table VI. has far more the character of an hyperbola with vertical asymptote than any type of frequency curve familiar to us. Accordingly the next stage in the work was to assume

$$y = Cx^{-n} \quad \dots \quad \dots \quad \dots \quad \text{(viii.)}$$

a type of curve which makes the ordinate infinite with zero light, and endeavour to get a better description of the results.

Using the same eight points of Table VI. and applying the method of least squares, we find

$$C = 557185{\cdot}77, \; n = 2{\cdot}2403.$$

Since n comes out positive and greater than unity, it follows at once that on the assumption made a curve of this kind leads to the number of stars in the universe being infinite.

If N_x be the number of stars of light more intense than x, then

$$N_x = \int_x^\infty y dx = \frac{C}{n-1} \cdot \frac{1}{x^{n-1}}$$

$$= 449234{\cdot}67/x^{1{\cdot}2403} \dots \quad \dots \quad \dots \quad \text{(ix.)}$$

Converting light into magnitude by means of the relation

$$x = 10000/(2{\cdot}51189)^m$$

we find

$$N_m = 4{\cdot}91217 \times 10^{{\cdot}49612m} \quad \dots \quad \dots \quad \text{(x.)}$$

This gives

$$\log N_m = {\cdot}49612m + {\cdot}69127$$

The agreement between the calculated and observed numbers of stars found by calculating the mid-ordinates and then multiplying by the light ranges is moderately good. It is less good if the areas are worked from (ix.), because we have fitted to mid-ordinates and not to areas. If we fit the area curve (ix.) directly to Newcomb's results by least squares we find

$$\log N_m = {\cdot}5296 \times m + {\cdot}5008 \quad \dots \quad \dots \quad \text{(xi.)}$$

Using stars to the fifth magnitude from this equation the following results were obtained :—

TABLE VII.

Number of stars of magnitude of less than	1·75	2·25	2·75	3·25	3·75	4·25	4·75	5·25	5·75	6·25	6·75	7·25
Observed after Newcomb ...	23	55	96	174	309	549	1011	1887	3355	5333?	...	...
Calculated ...	27	49	91	166	307	564	1038	1911	3516	6468	11,902	21,880

Here, again, the frequency increases too rapidly for the higher magnitudes, but the agreement is not a very bad one, and it indicates that a light frequency curve of type (viii.) is likely to represent approximately the actual relation between magnitude and frequency for the first part of the distribution. Since the curve rises too rapidly for high magnitudes, it seems to demand that the origin, and accordingly the asymptote, should not be taken at zero light. I assumed, therefore, that the curve was of the form

$$y = C/(x+b)^n \quad \dots \quad \dots \quad \dots \quad \dots \quad \text{(xii.)}$$

This curve at once suggests the possibility of determining whether the hypothesis of a limited or an unlimited number of stars best corresponds with the counts of stars of low magnitude. All extrapolation is, of course, only the vaguest suggestion, but the point seemed worth pursuing.

Unfortunately if we put (xii.) in the form

$$\log y = \log C + n \log (x+b) \quad \dots \quad \dots \quad \text{(xiii.)}$$

we see that the method of least squares does not lend itself to a ready determination of the constants C, n, and b.

I began by putting for C and n the values already found, and then determining by trial and error an approximate value for b. It was easy to see that the alteration in the origin would considerably better matters. Or the frequency of star-counts of the low magnitudes suggests that the number of stars in the universe may be finite. The next step in the work was to give the approximate values of the constants small variations and determine these by the method of least squares. But at this stage of the work Professor Pickering's recent important paper on the Distribution of the Stars* reached me. This not only provided much matter for consideration, but also the most recent star-counts, these being far more ample and accurate than those on which I had hitherto been working. It seemed, therefore, desirable to discuss the question of bettering the frequency fit by adopting (xii.) and calculating the constants on the basis of Professor Pickering's data.

A word must here be said of Professsr Pickering's own treat

* *Annals of Harvard College Observatory*, vol. xlviii. pp. 149–185.

ment of stellar frequency. He starts from an equation corresponding to my (iii.) and then modifies the constants B and A in the equation $\log N_m = B\,m + A$ to get a better fit. B would $= \cdot 60$ on the hypothesis of p. 447. Professor Pickering finds

$$\log N_m = \cdot 51m + \cdot 618 \quad \ldots \quad \ldots \quad \text{(xiv.)}$$

It will be noted that the value given above in (xi.) for N_m

$$\log N_m = \cdot 530\,m + \cdot 501$$

based on Newcomb's numbers does not—considering how widely these differ from Pickering's counts—diverge very considerably from Pickering's equation.

Starting from Pickering's counts the next stage in the work was first to better his constants by a rather more general method of curve-fitting, and then, on the basis of this first fit, to endeavour to improve matters by introducing a constant corresponding to the b of my equation (xii.). As in the previous investigation the relation between frequency and amount of light x was assumed to be of the form

$$y = Cx^{-n}$$

$$\text{whence } N_x = \frac{C}{n-1} \Big/ x^{n-1} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \text{(xv.)}$$

gives the number of stars with light greater than x.

I now fitted this curve by the method of least squares to the first fourteen entries in Pickering's Table XIV.,* that is, dealing with stars up to magnitude 6·5. The method of fitting was as follows:

$$\begin{aligned}\log N_x = \nu &= \log C - \log(n-1) - \overline{n-1}\,\log x \\ &= c - \log(n-1) - (n-1)\,\xi, \text{ say,}\end{aligned}$$

we have therefore to make

$$S_1^{14}\,\{\nu - c + \log(n-1) + (n-1)\xi\}^2 \text{ a minimum.}$$

The type equations of least squares are

$$S(\nu) - 14c + 14\log(n-1) + (n-1)S(\xi) = 0$$

$$S\{\nu - c + \log(n-1) + (n+1)\xi\}\left(\frac{1}{n-1} + \xi\right) = 0$$

or, using the previous equation,

$$S(\nu\xi) - cS(\xi) + \log(n-1)S(\xi) + (n-1)S(\xi^2) = 0$$

This gives us

$$S(\nu)S(\xi) - 14S(\nu\xi) = \overline{n-1}\,\{14S(\xi^2) - S(\xi)S(\xi)\}$$

which determines $n-1$, and then c is given by the first equation.

* *Loc. cit.* p. 168

Now $\xi = \log x = 4 - \cdot 4m$* determined ξ; ν = logarithm of Pickering's counts, and the remainder is only arithmetical calculation. There resulted :

$$n = 2{\cdot}27737$$
$$C = 665732{\cdot}88$$

or the relation between luminosity and stellar frequency is

$$y = 665732{\cdot}88x^{-2{\cdot}27737} \quad \ldots \quad \ldots \quad \text{(xvi.)}$$

i.e. the *area* of this curve up to a given value of x from ∞ represents the total number of stars with a luminosity greater than x. Converting light into magnitude in order to compare with Pickering's equation we find

$$\log N_m = {\cdot}51096m + {\cdot}60737 \ldots \quad \ldots \quad \text{(xvii.)}$$

There is thus a modification of about 2 per cent. in the constant term.

The following table gives a comparison of the numbers obtained from the above formula and Pickering's numbers on the basis of Pickering's table (XIV.).

TABLE VIII.

Calculated and Observed Stellar Frequencies.

Up to Magnitude.	Observed No. of Stars.	Pickering's Formula. Total.†	Pickering's Formula. Residual.	Present Formula. Total.	Present Formula. Residual.
·25	5	6	+ 1	5	0
·75	10	10	0	10	0
1·25	18	18	0	18	0
1·75	32	32	0	32	0
2·25	58	58	0	57	− 1
2·75	105	105	0	103	− 2
3·25	193	189	− 4	185	− 8
3·75	336	339	+ 3	334	− 2
4·25	589	610	+ 21	601	+ 12
4·75	1067	1098	+ 31	1083	+ 16
5·25	1972	1975	+ 3	1949	− 23
5·75	3562	3552	− 10	3511	− 51
6·25	6284	6390	+ 106	6322	+ 38
6·75	11004	11495	+ 491	11385	+ 381
7·25	17955	20654	+ 2699	20505	+ 2550
Mean square root residual up to and including magnitude 6·75			135	...	103

* See p. 450, $x = l = \dfrac{10000}{(2{\cdot}51189)^m}$.

† I differ from a considerable number of Pickering's calculated values, supposing him to have determined them from (xiv.) above. See his p. 167.

I think, therefore, that we may conclude that a somewhat better result than Pickering's, but of the same form, can be obtained to represent his counts. But this result still indicates the point noted above, *i.e.* that a formula of type (viii.) gives too great a frequency after we have passed the limit of the lucid stars. Both forms of the equation give results diverging fairly rapidly from observed numbers after magnitude 6 has been passed.

Using the improved form of Pickering's formula, I now turned to the problem of substituting equation (xii.) for (viii.). Recognising the fact that b can only mean a small modification in x, I retained at first the same values of C and n as I had found before, and gave b the series of values recorded in Table IX.

TABLE IX.

Effect of Limiting the Number of Luminous Stars.

Value of b.	Mean Square Root Residual.	Total Number of Stars.
0	103	Infinite.
·1	83	9,870,820
·2	67	4,072,178
·3	51	2,426,012
·4	40	1,679.964
·5	40+	1,263,310

We see from this table that a very slight alteration in the value of b produces an enormous difference in the total number of stars. While the agreement between observed and calculated frequencies, as shown by the mean square-root residual, improves steadily as we raise b from 0 to ·4, the total number of stars diminishes from infinity to 1,679,964, a result obviously far too small.

Or if we use the formula

$$y = 665732{\cdot}88(x + {\cdot}4)^{-2{\cdot}27737} \quad \dots \quad \dots \quad \text{(xviii.)}$$

to connect frequency $y\delta x$ with luminosity x, we shall have a result for the number of lucid * stars more than three times as good as Pickering's † equation ; but this improvement is at the cost of limiting the total number of luminous stars to about a million and a half.

Taking Pickering's counts against the numbers obtained from (xviii.) we have Table X. The agreement is certainly noteworthy, considering that we are fitting a curve with only three constants to fourteen points, or rather areas.

* Including under the term "lucid" all stars less than 6·75 in magnitude as being possibly visible to some naked eyes.

† Mean square residual less than 40. Pickering's numbers give 135.

TABLE X.

Distribution of Stars.

Up to Magnitude.	Observed Number.	Calculated Number.	Difference.
·25	5	5	0
·75	10	10	0
1·25	18	18	0
1·75	32	32	0
2·25	58	57	− 1
2·75	105	103	− 2
3·25	193	185	− 8
3·75	336	333	− 3
4·25	589	600	+ 11
4·75	1067	1078	+ 11
5·25	1972	1937	− 35
5·75	3562	3476	− 86
6·25	6284	6222	− 62
6·75	11004	11102	+ 98
7·25	17955	19703	+ 1748

I then proceeded to modify the C and n constants on the assumption that $b = ·4$ is approximately the correct value. I found $y = 667026/(x + ·4)^{2·27692}$, or

$$\log N_x = 5·7179792 - 1·27692 \log (x + ·4) \quad \dots \quad \text{(xix.)}$$

TABLE XI.

Allowance for Periodic Variation from Simple Law.

Up to Magnitude.	Value of n from Count.	Observed Number of Stars.	Calculated Value from (xix.).	Δ (xix.).	Calculated Value from (xx.).	Δ (xx.).
·25	1·28691	5	5	0	5·5	+ ·5
·75	1·27511	10	10	0	10	0
1·25	1·27503	18	18	0	18	0
1·75	1·27658	32	32	0	31	− 1
2·25	1·27561	58	57	− 1	56	− 2
2·75	1·27466	105	103	− 2	105	0
3·25	1·27110	193	186	− 7	192	− 1
3·75	1·27637	336	335	− 1	338	+ 2
4·25	1·28119	589	602	+ 13	589	0
4·75	1·28002	1067	1083	+ 16	1062	− 5
5·25	1·27314	1972	1946	− 26	1959	− 13
5·75	1·27170	3562	3490	− 72	3560	− 2
6·25	1·27518	6284	6246	− 38	6281	− 3
6·75	1·28105	11004	11142	+ 138	11003	− 1
Mean square-root residual	...	...	...	44*	...	3·9

* This value is rather larger than that given by (xviii.), but the formula gives a considerably better result up to magnitude 6·25.

In Table XI. we have (*a*) the values given by this formula, (*b*) the values of the constant $(n-1)$ of the logarithmic term, which would in each case give the observed counts. If these values of n be plotted to the magnitudes, a periodic deviation from the mean value of n at once becomes visible. The period is nearly 2·5 magnitudes with maxima at 2, 4·5, 7 magnitudes, and *roughly* an amplitude of about ·00510.

We may accordingly take

$$\left.\begin{aligned} \log N_x &= 5{\cdot}7179792 - n_m \log (x + {\cdot}4) \\ \text{where} \quad n_m &= 1{\cdot}27692 + {\cdot}00510 \cos 2\pi\left(\frac{m + {\cdot}5}{2{\cdot}5}\right) \end{aligned}\right\} \quad \ldots \quad \text{(xx.)}$$

No doubt an even better fit could be obtained with a little trouble, but the mean square-root residual is so small that a closer approximation in the present state of the counts is hardly worth attempting.

Hence I think we may conclude that, confining our attention to the lucid stars (*i.e.* $m < 6{\cdot}75$), the frequency distribution of magnitudes is more closely reached on the assumption that the number of stars belonging to this group is limited. Further, there appear to be periodic deviations from a formula of the Pickering type, allowance for which enables us to reduce his mean square-root residual from 135 to 3·9. The latter residual is probably well within the error of the counts.

We have seen that, while we confine our attention to the lucid stars, there is no sensible correlation between magnitude and distance by which distance increases in any way proportionately with magnitude. At the same time, there appear to exist sensible deviations from the mean parallax which are beyond the errors of random sampling. These deviations (fig. 1) have, roughly, a period of about five magnitudes from maximum parallax to maximum parallax. This is about double the period noted in the frequency of the lucid stars. Thus we have the suggestion, even if it be only of the vaguest kind, that the bulk of the lucid stars may belong to a separate universe within which magnitude is not mainly determined by parallax or distance, but is more closely associated with colour, and thus probably with chemical or physical condition. It is suggested that the relation of magnitude to spectroscopic class may be far more important than that of magnitude to distance, and I propose in the near future to form contingency tables of magnitude and spectroscopic classes.

5. *General Summary.*

(*a*) Any character of a star which may be supposed to follow a chance distribution of frequency would enable us, if the "tail" of the distribution were known, to form some estimate of the total number of stars.

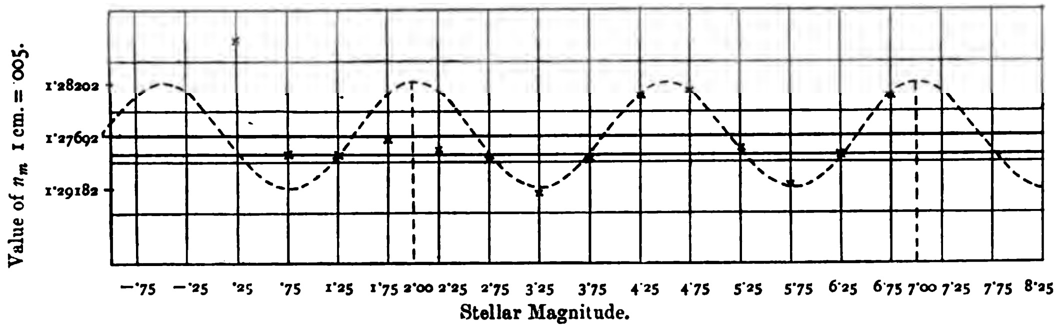


FIG. 3.—Periodicity in Value of n_m.

N.B.—No attempt must be made to judge the accuracy of fit of the periodic curve beyond the limits of magnitude of 2·25 to 7·00. Below 2·25 the whole amplitude of n does not denote the alteration in the frequency by a single star. The correspondence between 2·5 and 7·0 is that upon which weight is here placed. Pickering's constant value of n^m is 1·275.

(*b*) The only character which appears to be at present available is magnitude; but magnitude is a physiological rather than a physical character, and the chance distribution must only be applied to quantities of the latter kind.

(*c*) An investigation was first made of the relation between magnitude and distance. So far as the lucid stars are concerned there appears, on the basis of parallaxes at present determined, to be no decrease of parallax with increase of magnitude. There is no sensible correlation between the two. A sensible relation was found between parallax and proper motion sufficient to indicate that parallax is really a measure of relative distance, but the relation was not intense enough to enable any useful prediction of parallax to be made from a knowledge of proper motion. On the other hand, both visual and photographic magnitudes were found to be sensibly associated with colour. Investigating further the relation between parallax and magnitude, it seems probable that definite variations of parallax are associated with magnitude, and are possibly of a periodic character; but a continuous change of one character with the other is not appreciable—at any rate on the present data—so far as the lucid stars are concerned.

(*d*) Taking light as the variable, it was found that no curve approaching the Gaussian type could possibly give the frequency of stars for various quantities of light. The general type of the distribution was seen to be of the form

$$y = \mathrm{C}/(x+b)^{n}$$

If we put $b = 0$, this gives us, when we replace light by magnitude and y by $\mathrm{N}_x = \int_x^\infty y\,dx$, the form

$$\log \mathrm{N}_x = \mathrm{C}' + n'm$$

where m is the magnitude and C' and n' are constants. This form may be directly deduced by the assumptions—

(1) That Fechner's law in *its simplest form* holds;

(2) That magnitude varies inversely as the square of the distance;

(3) That the stars are scattered uniformly through space.

All these hypotheses are almost certainly erroneous, yet it is remarkable how closely their combined errors give the true result. Pickering has already considered the application of a formula of the above kind, and shown that it still approximates to the observed frequencies.

Pickering's formula can be made to give better results, in the ratio of 135 to 103 (testing by the residuals), by choosing somewhat different constants. It can be improved in the ratio of 135 to 40 by supposing b is not zero, or that the number of stars of the system to which the lucid stars in the main belong is not infinite. It is then seen that the deviations in the

frequency from the proposed formula are fairly closely periodic, the period being 2·5 magnitudes. In this manner the calculated frequencies up to magnitude 6·75 can be obtained with a mean square-root residual of less than four stars. Greater exactitude can hardly be hoped for until the probable error of the counts is far less than at present.

(*e*) The general conclusion is reached that magnitude is not, so far as the lucid stars are concerned, mainly, if at all, a question of distance. The arrangement of these stars differs from a pure random distribution throughout space, based upon magnitude as a function of distance, by a periodic variation in frequency which appears somewhat similar, although of only half the period, to that which occurs in the relation of parallax to magnitude. Further, a better fit is obtained for the frequencies of the lucid stars if we assume the asymptote to the frequency curve not to be at zero light. This suggests that the system to which the lucid stars belong may possibly be a limited system of a definite and not random structure.

This work was undertaken in the Drapers' Company Statistical Laboratory at University College, London, and I have to thank the staff there for suggestions and assistance during the progress of the work, in particular Mr. J. Blakeman, M.Sc., for aid in the very laborious calculations of which only the results appear in this paper.

Errata in Monthly Notices, vol. lxiv. No. 6.

Page 554, 1906, Arguments vi. and vii. should be transposed.
" 557, 1906, B *should read* 35° 48′ 48″·12.
" " 1907, log *c* " " 9·57334945.

Erratum in Annual Report, 1906.

In the Council Note on Groombridge's Catalogue the following should be inserted after "and probably a few others" (p. 231, line 18): Hornsby's observations would take an honourable place in the list.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXVI. JUNE 8, 1906. No. 8

W. H. MAW, Esq., PRESIDENT, in the Chair.

John de Fenton, Ph.B., Seymour Avenue, Parktown, P.O. box 1050, Johannesburg, South Africa;
John Grigg, The Observatory, Thames, New Zealand; and
Robert Leetham Jones, M.A., 3 King's Bench Walk, Temple, E.C.,

were balloted for and duly elected Fellows of the Society.

Professor Julius Franz, Observatory, Breslau, Germany, was balloted for and duly elected an Associate of the Society.

The following Candidate was proposed for election as a Fellow of the Society, the name of the proposer from personal knowledge being appended :—

Alexander Davidson Fleming, Artillery Mansions, 75 Victoria Street, S.W. (proposed by the Rev. D. Fleming).

Sixty-seven presents were announced as having been received since the last meeting, including, amongst others :—

Sir W. Huggins, The Royal Society, presented by the author; Report on the Geodetic Survey of Rhodesia, presented by Sir D. Gill; 18 charts of the Astrographic Chart of the Heavens, presented by the Royal Observatory, Greenwich; and 10 charts presented by the San Fernando Observatory.

On Mr. Cowell's Discussions of Ancient Eclipses of the Sun.
By Simon Newcomb.

In his various papers discussing Greenwich observations of the Moon, Mr. Cowell has made so important a step in advance in the method of deriving results from a long series of observations, and in unravelling the intricate network of mutual relations between the quantities he has to investigate, that any conclusion he reaches in this field must carry great weight. This fact seems to render it all the more desirable to make a critical examination of his conclusions when his methods seem so open to question as do those adopted in his two papers, "On the Secular Acceleration of the Moon's Longitude and Node" and "On the Secular Acceleration of the Earth's Orbital Motion" (*Monthly Notices*, vol. lxv. p. 861 and vol. lxvi. p. 3).

I begin with a glance at the available material. Historical research has brought to light some forty or more records or statements, extending between B.C. 1069 to A.D. 200, which may be considered with a greater or less degree of probability to refer to eclipses of the Sun. In most cases the conclusion that an eclipse is referred to is undoubted; the other cases range through every degree of doubt from plausibility to absolute uncertainty. The date is frequently so doubtful that the identification of an eclipse is more or less uncertain, even when granted that an eclipse was referred to.

Several recent investigators, Airy, Hansen, Oppolzer, Ginzel, and now Cowell, have investigated various selections, generally from three to five, of these eclipses with a view of deriving corrections to the secular motions of the Moon's elements. But there is no agreement between any two of the authors except, perhaps, Airy and Hansen; and no one of the results agrees with conclusions derived from modern observations by the aid of gravitational theory. Yet there is no reason to impugn the correctness of the narrative when we measure correctness by the standard of the historian. As I have said, in the majority of cases the eclipse is so far identified as to show that the statement of the historian was well founded. But it does not follow from this that the eclipse can be utilised for any astronomical purpose. As I have repeatedly pointed out, there being no observations of times or phases, the only fact we can take as the base of a conclusion is that a well-identified eclipse was total at a known place. By a curious fatality there is always some weak point in each of the small number of cases in which this condition is presumably satisfied by the narrative. In other cases the (as it seems to me) gratuitous assumption has to be made that the eclipse was total at the point where the record was discovered, or where the historian was supposed to have lived.

In the *Monthly Notices*, vol. lxv. p. 61, Mr. Cowell discussed five of these thirty or forty eclipses, and found, on the assump-

tion that each was total at a given place, that the whole five could be represented by a correction to the secular acceleration of the Moon's node, the reality of which would involve the conclusion that, in ancient times, the annual motion of the node was about $1''\cdot8$ different from the result of gravitational theory. As the correctness of gravitational theory at the present time is proved by Brown's researches, this conclusion would imply that a law of nature was different in ancient times from what it is now.

In the *Monthly Notices* for November 1905 Mr. Cowell accepts the inadmissibility of this conclusion, and shows that his eclipses can also be represented by supposing a sidereal secular acceleration in the mean longitude of the Sun of $+4''\cdot1$. In view of the fact that no such acceleration is shown by 150 years of modern observations of the Sun, and that if it exist it must be due to some other cause than gravitation, it would seem to require a good deal of proving. To test the sufficiency of Mr. Cowell's proof we must consider his evidence in detail.

His first eclipse is one recorded as occurring at Babylon −1062 July 31. Although the record does not distinctly state that the phenomenon was actually observed at Babylon, the presumption that such was the case is fairly plausible. In affording even a plausible conjecture of totality at a definite place this eclipse seems to me exceptional.

In his No. 2, recorded at Nineveh, nothing is said in the record about the eclipse being total. If we accept the modern tables as correct the southern limit of totality passed about sixty miles north of Nineveh. I see nothing unlikely in the hypothesis that this eclipse, supposing it thus to have occurred as our modern tables show, should have been recorded at Nineveh, as it must have been very striking at that point.

His eclipse No. 3 is that of Archilochus in −647. Here we have nothing to base a conclusion upon except that a certain writer vaguely mentions what undoubtedly were the phenomena of a total eclipse, but without indication when or where the phenomena occurred. It seems to be doubtful even where Archilochus lived, as Ginzel says he probably lived either at Pharos or Thasos. The identification of the description with the eclipse of −647 seems to be little more than a plausible conjecture. The only conclusion which it seems to me can fairly be drawn from the record is that at some time in the seventh century B.C. there occurred a total eclipse at some point near enough to the residence of Archilochus to admit of his hearing about it.

Eclipse No. 4 is that of Thucydides −430. This was an annular eclipse by our tables; but I see no reason for inferring that the eclipse was fully annular at Athens.

The fifth and last eclipse is that of Tertullian at Utica. Of this eclipse the writer says that it was not quite total—*extincto pene lumine.* This statement of the historian is quite in accord

with the tables if the latter indicate that the total phase passed anywhere near Utica. But in order to reach a conclusion Mr. Cowell assumes that the writer meant something different from what he says, and that the eclipse was total at Utica.

By these interpretations five of the six authorities are brought into unanimity. But how is this unanimity reached? In the most unambiguous record the interpretation put upon it is only a plausible one; the totality of the second and third eclipses at the assigned places is largely hypothetical; in the fourth, which was annular, the conclusion is doubtful; and the last witness was interpreted as meaning something different from what he said—that is to say, an eclipse which he distinctly describes as not total was assumed to be total. Unanimity reached in this way does not seem to me a sufficient basis for a conclusion so far-reaching as a secular acceleration of 4″ in the mean longitude of the Sun.

I may advert to another phase of the subject—the relation of the question to the tidal retardation of the Earth. The apparent acceleration arising from this cause results in a reaction of the Earth on the Moon causing a proportional retardation of the latter. The amount of this retardation is easily computed, and the result is found to be a diminution of the apparent increment of the acceleration of about $\frac{1}{12}$ part of its entire amount. Nothing can therefore be based on this reaction.

Two phases of the subject are alluded to by Mr. Cowell in the *Monthly Notices*, vol. lxvi. pp. 5, 6. He there alludes to my non-use of the observed magnitude of the Ptolemaic eclipses of the Moon. On this it will suffice to remark that I should regard it as assigning an unwarrantable degree of precision to the observations to suppose the magnitude of the eclipses precise to $\frac{1}{10}$ part of the Moon's diameter. This uncertainty corresponds with one of 180″ in latitude, or more than half a degree in the longitude of the node. In view of the fact that the longitude of the node at the time of these eclipses can probably be fixed from modern observations within 1′ it does not seem worth while to consider observations the probable error of which is 30′.

Mr. Cowell also alludes to the case of a Ptolemaic eclipse in which, as I said at the time, if my corrections be real, the Moon must have set at Babylon before the eclipse was total. In this he seems to be unaware that it was pointed out by Oppolzer that the record did not state that the observation was made at Babylon, as I had wrongfully supposed, but left open the easy inference that it was observed on Grecian territory.

On the whole Mr. Cowell's conclusions seem to me in need of better evidence than that which he adduces; and one might also fairly inquire whether it is sound to confine the discussion to six out of twenty or thirty real or supposed eclipses.

On Ancient Eclipses. By P. H. Cowell.

Two papers have lately appeared in the *Monthly Notices* in criticism of the conclusions that I have drawn from ancient eclipses.

I have read Mr. Nevill's paper with the greatest possible interest: he takes the standpoint that the question is one to be settled by the evidence, and not by preconceived theory, and he brings forward a large number of additional eclipses with which he tests my conclusions. I intend, therefore, to perform as soon as possible my own calculations upon these eclipses. I shall supplement Mr. Nevill's results by giving the least distance between the centres of the Sun and Moon as seen from a specified place, with symbolical corrections for the unknown quantities whose values are to be determined. At the present time, before these calculations are ready, I can offer only a few general remarks.

1. I did not choose the date −647 for the eclipse of Archilochus, but found it already assigned, and I adopted it without further inquiry. I now admit the force of Mr. Nevill's reasoning, and the eclipse must therefore be relegated to the same category as the eclipse of Agathocles.

2. Sivan was the third Babylonian month. If, therefore, July 31 was the end of Sivan, the year must have begun about May 4, and the month that began on April 4 was presumably an intercalary month. The equinox fell about March 31, and the difficulty is, therefore, only one of a few days, and not of one or two months, and consists in the question, Why was April 4 not recognised as subsequent to the equinox? But in any case errors in the calendar which might be impossible a few centuries later are not necessarily inadmissible at an earlier time. I understand that Mr. Nevill's alternative of relegating the eclipse to the twelfth century does not find favour with Mr. King. Mr. Maunder is sending an interesting note on this question to the July number of *The Observatory*.

3. Thucydides was an Athenian writing principally for Athenians. I consider the probability great that he either saw the eclipse at Athens himself, or that—if the phenomenon was different at Athens from what he described—some of his friends would have told him so.

4. In the case of the first twelve eastern eclipses given by Mr. Nevill I find in *M.N.* xxiv. p. 42, the statement that the eclipses of −708 and −600 are alone described as total. For these two eclipses, as well as for those of −180, −187, and −299, subsequently given by Mr. Nevill, my system does very well, and distinctly better than any of Mr. Nevill's three systems. The eclipse of −381, as pointed out by Mr. Nevill, fits no system of corrections.

5. Mr. Nevill makes no allusion to the lunar eclipses of the Almagest, which support my conclusions.

6. I have, of course, referred to the observations of the Sun during the last 150 years. It goes without saying that I do not maintain the value $4''\cdot1$, which I find for the secular accelerations of the Sun is correct to $0''\cdot1$. A very slightly smaller secular term might easily be masked by the errors of personality that we know to exist. I have still the further loophole that there may exist an unknown term of 300 years' period and coefficient $1''$ in the Sun's longitude. (If the unknown term in the Moon's longitude is to be attributed, as Professor Newcomb once supposed, to an inequality in the Earth's rotation, a term of the required period, amplitude, and phase must necessarily exist in the Sun's longitude.)

7. I should like to raise the question as to how eclipse calculations should be presented. I prefer to resolve in longitude and latitude, at right angles to the line of sight. Mr. Nevill and many others resolve along the surface of the Earth, and tell us that according to certain tables the central line passed so many degrees north or south of a certain place. This mode of presentation is complicated by the effects of foreshortening, and we cannot tell, without considerable labour, what would be seen from the place chosen for calculation. It is obvious also that it is far easier to carry through suggested modifications of the tables in my mode of presentation than in Mr. Nevill's. I should also like to ask whether it is not worth while to give some intermediate steps in the calculation. In my first paper on solar eclipses in five pages I gave for five eclipses full formulæ and a great many intermediate steps in the calculations. Any-one who wishes to repeat my calculations can do so without any further work of reference than a table of logarithms. He can see clearly what terms I have retained and what I have neglected as unimportant. At intervals, in no case exceeding half an hour, he can say, as the case may be, "So far the calculations are numerically correct" or "An error of calculation has been introduced at this point." Lastly, if he wishes to modify my secular accelerations or other parts of my formulæ, he can do so in a few minutes. On the other hand it is impossible for me to supplement Mr. Nevill's calculations without repeating his entire work from the beginning. I very much regret this, as I have found his paper most interesting, and I deplore the unnecessary delay before I can make full use of it.

Professor Newcomb has now published a second note. It must be obvious that neither of these notes contains the features which render Mr. Nevill's paper so valuable. I find his position as to the evidence extremely difficult to understand, for he begins by saying that part of the evidence is absolutely uncertain, and he ends by asking whether it is sound not to have used more of it. I picked out what in my judgment was the best evidence, and I found it accordant upon an excessively simple geometrical hypothesis.

I need not follow him in detail through all the eclipses. I

should never have thought of basing my conclusions on any two of them. I base my conclusions on the coincidence of all of them. A proof from coincidence is like circumstantial evidence in a criminal trial. It is unnecessary when enough direct evidence is to be had, but it is often of great force.

As for the lunar eclipses, there should be no great difficulty in estimating the magnitude to the nearest tenth of a diameter, with a probable error of one-fortieth. In ten cases magnitudes are recorded. In nine cases they indicate a large correction to the distance between the node and the Sun, always of the same sign and averaging over 1000″.

In nine of the nineteen lunar eclipses no numerical estimate of magnitude is on record. They are therefore useless for my special purpose. No. 8 is one of these. In this case Professor Newcomb has accidentally interpolated the words "at Babylon" in what purports to be a translation of Greek. No such words occur in the Greek. Other less important discrepancies between Greek and English occur in Nos. 16, 17, and 18. It does not follow that I am unaware of a mistake because I have not alluded to it, more especially as in this case eclipse No. 8, and everything connected with it, is irrelevant to the main issue.

The calculations referred to at the beginning of this note are by now sufficiently far advanced for me to make the following statements:—

1. The eclipses of −1123, −1116 and −1069 cannot possibly (that is to say, by any moderate alterations of the tables) have been total at Babylon. If, therefore, "fire in the midst of heaven" implies a total eclipse at Babylon, the date is −1062.

2. The eclipse of −609 cannot have been total at Larissa; and the eclipse of −602 was total at Larissa according to my formulæ.

3. The eclipse of −584 will do perfectly well for the eclipse of Thales. According to my formulæ, the time of maximum eclipse occurred a few minutes before sunset.

Note on Polarisation Phenomena in the Solar Corona, 1905 *August* 30. By H. F. Newall.

The present note is presented in compliance with a request from the President. It contains an attempt at a brief *résumé* of the chief results of the observations made by the expedition of which I was in charge at Guelma relating to the phenomena of polarisation of the corona of 1905 August 30, so far as they can be stated apart from the complete measurement and study, which I hope to be able to make during the summer, of the photographic records.

It has, as I gather, been felt that the results of eclipse expeditions as given in the preliminary reports of observers are in

danger of being lost amongst the paragraphs relating to the itinerary of the expeditions and to the details of instruments used. It seems impossible to omit the itinerary from such reports; for I think no observer on his return home can fail to wish to acknowledge publicly his obligations and indebtedness to the many persons at home and abroad from whom he has received assistance and kindness in a measure that is always surprising, however often the experience is repeated. The details about instruments are undoubtedly in very many cases of great use to observers, and can scarcely be omitted without serious loss. But without doubt the scientific interest of the observations runs the risk of being obscured in the present system of preliminary reports; and it seems desirable to find some opportunity of discussing the observations apart from details of the expedition and simply in relation to the object of the observations, and that it should be found at a date much earlier than that of the completion of the final reports. Hence the invitation which led to the preparation of the present note.

I endeavour to summarise some of the results of the Guelma expedition by arranging them in sections dealing with (i.) the atmospheric polarisation, (ii.) the polarisation of the corona, and (iii.) general considerations.

Polarisation of the Light Scattered by the Earth's Atmosphere.

(*a*) My visual observations with a Savart polariscope showed that the plane of polarisation of the light from the sky over a field of view approximately 24° in diameter, with the corona at the centre, was either very nearly vertical or very nearly horizontal. The mean of two readings, differing by 5° from each other, indicated that the plane of polarisation was inclined either at $5\frac{1}{2}°$ to the vertical, sloping downwards to the left, or else at $5\frac{1}{2}°$ to the horizontal, sloping downwards to the right. The photographs unmistakably eliminate all doubt as between these choices, and show that the atmospheric polarisation was in the nearly horizontal plane. This observation is at variance with that of M. Salet, who, observing within thirty miles of Guelma, noted that the atmospheric polarisation was vertical.

Visual observations further proved that there was no marked change during the whole of the total phase of the eclipse at Guelma.

(*b*) Photographs taken with the Savart camera prove that the polarisation of the atmosphere was horizontal or nearly so, and that the polarisation of the corona was radial.

The polarisation is shown by the existence of marked bands—alternations of great and small intensity—over the corona and over the sky.

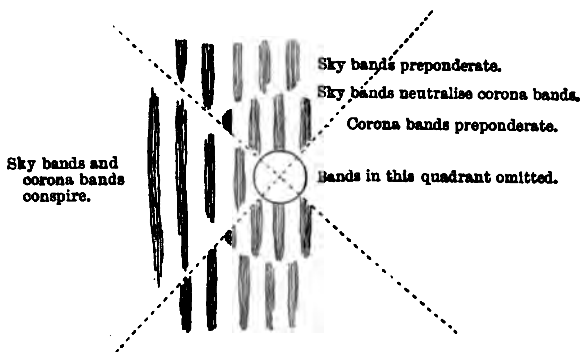
If we regard the corona as divided into four quadrants by two diameters drawn at 45° to the vertical, we may speak of the quadrants as upper, lower, right-hand, and left-hand. I refrain

at present from specifying the quadrants in terms of precise position angles to be deduced from measurements of the photographs, because I wish to avoid the need, which would almost certainly arise, of revising preliminary numbers and of giving corrections in the final discussion; for this would lead to confusion.

The general results may be stated in this wise:—

The polarisation of the corona is shown to be approximately radial by the fact that the Savart bands (which were set very nearly parallel to the vertical diameter) in the upper and lower quadrants are out of step with the bands in the right-hand and left-hand quadrants.

The approximate horizontality of the polarisation of the atmosphere or sky is shown by the fact that the vertical bands in the outlying parts of the photograph are out of step with the coronal bands in the upper and lower quadrants, and in step with the coronal bands in the right-hand and left-hand quadrants. Diagrammatically the effects may be represented thus:—



Rough representation of distribution of Savart bands over sky and corona.

In the upper and lower quadrants the sky bands neutralise the corona bands at a distance of about $\frac{3}{4}°$ from the centre of the corona. This means that from the veil of illuminated sky between the observer and the corona there came as much polarised light as came from that part of the corona which is about $\frac{3}{4}°$ from the centre, in the upper and lower quadrants. This seems to me to be a result of very considerable importance in our interpretation of these and other phenomena of the corona.

(*c*) The photographs taken with the Nicol camera afford a final corroboration, if anything further is wanted, of the conclusion that the atmospheric polarisation was approximately horizontal. The actinic effect of the sky is clearly shown on the negatives by contrast with the absolutely transparent edges of the negative where the film was protected from the light by a diaphragm in the camera close to the plate. The four plates of

the series were simultaneously developed until there was danger of masking detail of the corona by bringing out the general brightness of the sky, and it should be added that in every detail of manipulation of the plates scrupulous care was given to subject them all to simultaneous and identical treatment. Now the series shows that the effect of the sky is smaller in that plate which was taken with the Nicol set to transmit the light polarised in a vertical plane than in either of the two other plates taken with the Nicol set so as to transmit light polarised in planes at 45° to the vertical on either side of it. It is thus clear that the sky polarisation was in the nearly horizontal plane.

The evidence along these lines is set forth rather fully, because it has generally, I believe, been held that the atmospheric polarisation was in a vertical plane and not of such intensity as to be likely to obscure the interpretation of the phenomena of coronal polarisation.

I have ventured in my preliminary report to "hazard numbers on memories," and have given a table similar to the following :—

	Atmospheric Polarisation.			Plane of Polarisation.
1898 India	Intense	10	Dry air	Probably not vertical.
1900 Algiers	Fairly strong	7	On the sea board	Vertical.
1901 Sumatra	Imperceptible	0	Moist air	Indeterminate.
1905 Guelma	Rather weak	3	Dry air	Nearly horizontal.

There is little doubt but that character and intensity of the atmospheric polarisation vary considerably at different eclipses, and that a knowledge of them is of importance when questions relating to the outer parts of the corona are considered.

Polarisation of the Corona.—The interest in the study of the polarisation of the corona is of course to decide what are the relative proportions of polarised and unpolarised light in the different parts of the corona.

Systematic measurement is the only way to arrive at a solution, and the photographs which we were fortunate enough to get at Guelma are well suited for this study.

All the evidence afforded by the photographs taken both with the Savart Camera and with the Nicol Camera fits in with the view that the polarised portion of the light of the corona is radially polarised.

There is strong evidence on the Savart photographs that the polarisation is quite considerable even near the limb of the Sun. On the Nicol photographs, however, it would be much more difficult to establish this point with respect to the inner corona, simply because the density of the silver deposit for the inner corona is so great that a considerable change in the intensity of the light would be needed to make much change in the density of the silver. It is a great merit of the Savart method that the

comparison of a single "polarised" photograph with an "unpolarised" photograph gives the means of estimating the difference in density in the maxima and minima in the system of bands, and so of comparing "half unpolarised + polarised" with "half unpolarised + no polarised."

In the photographs which I secured in the Sumatra eclipse of 1901 there is marked evidence of considerable polarisation close to the limb—I mean within 1′ of the limb. In photographs obtained last year in Algeria the brightness of the corona and the longer exposures given to the photographs rendered the evidence less conspicuous, but it is there, quite marked at 3′ from the limb, and I think visible nearer in.

It seems well to call attention to these points, because this evidence is, I believe, at variance with that of Mr. Perrine in Sumatra, 1901, and with that of Dr. N. E. Gilbert at Guelma, Algeria, 1905.

Polarised Spectra of the Corona.—The photograph taken with a single-prism spectrograph, which had a large double image prism in front of the camera, has two pairs of spectra; one of these pairs is polarised tangentially, the other radially. They were taken at one exposure, the image of the corona and the dark Moon being thrown on the slit, in such a way that the slit was an approximately vertical diameter of the Sun. There is a marked difference in the intensities of the tangential and radial components.* The radially polarised spectra not only extend both further from the Moon's limb and also further into the ultra-violet, but are also considerably stronger than the tangentially polarised spectra. The spectra were photographed with a narrow slit, and though comparison spectra of the Sun taken with identically the same adjustment and width of slit show the Fraunhofer lines distinctly, yet no trace of such dark lines is to be found in the spectra of the corona.

Experiments made in the spring of this year show that dark lines can be detected photographically when a mixture of one part of sky light with three parts of continuous light from a gas flame is passed into the spectrograph. Hence one is led to believe that if the polarised light in the corona were reflected sunlight it should be detected in these polarised spectra, if the

* In reference to a question raised by Professor A. Fowler at the meeting at which a short account of this paper was given, I should like to add the following note. Shortly after the eclipse, with the instrument in exactly the same state as during the eclipse observations, photographs of the sky and of the Sun were taken with the special object of showing at a glance the effect of the single prism in producing polarisation. Even had the prism been such that the angle of incidence was the angle of complete polarisation of the reflected light, then the polarised portion of the transmitted light would have been 20 per cent. of the whole transmitted. The photographs of the unpolarised sources show a just perceptible difference between the polarised components, less in fact than I should have anticipated for components in the ratio of about 2 : 3; whereas the difference in the case of the corona photographs is very marked.

proportions of polarised sunlight amounted to one-sixth of the intensity of the unpolarised light usually attributed to incandescent matter. The spectra extend to about 5′ or 7′ from the limb, viz. to a distance where the Savart photographs indicate a proportion of more like one part of polarised light to one of unpolarised (estimated), and it is difficult, therefore, not to imagine either that there is some as yet unrecognised source of polarisation which will fit in with the marked absence of Fraunhofer lines in the spectra, or else that there is some condition of scattering which somehow obliterates the dark lines from the scattered light without depolarisation. We must be careful not to adopt any explanation of the absence of dark lines that would carry with it the obliteration of such lines from direct sunlight also.

Signs of Selective Polarisation in the Corona.—The photographs got with the Nicol prism show in a preliminary inspection that different parts of the corona are very differently affected by cutting out one of the polarised components of the light. Thus it would appear that in the quadrant on the east of the south pole of the Sun there are signs that while some of the bright arches which the researches of Christie and Dyson and others seem to prove to be connected in some way with the outburst of prominences, and which may perhaps be fitly called prominential arches, are equally strong in both components of polarised light, and are thus shown to be shining with inherent light, yet other parts of the corona, notably the streamers, which become straighter as they recede from the Sun's limb, are much stronger in the radially polarised component, and are thus shown to owe their visibility probably to reflected light.

General Considerations.—It is clear that no real advance in the interpretation, or even in the statement, of the phenomena recorded in the Guelma photographs is possible until complete measurements, such as I have in part planned, are made.

If we attempt to make deductions from the equality of the polarised light scattered by the sky and by the corona at a distance of about a diameter and a half from the limb we are at once stopped by the need of quantitative knowledge. Turner's law (inverse sixth power of the distance from the centre), if it were true up to four radii, would indicate that the intensity of the corona is at that distance $\frac{1}{4096}$th part of the intensity at the limb. But the law relates to the brightness of the combined polarised and unpolarised light of the corona. For further progress we need to know the relative quantities of these components.

If we attempt to attribute the atmospheric polarisation to scattering of the integrated light of the corona, it is clear that any resultant polarisation must be due to want of symmetry in the corona. And so symmetrical a corona as that of 1905 could hardly give resultant polarisation of the relative intensity indicated by the strength of the Savart bands seen in my visual

observations. On the other hand, if the observed polarisation were attributed to secondary scattering in the atmosphere of light coming from the landscape or air in the neighbourhood of the edge of the shadow of the Moon, we should expect to have a change in the phenomena as the shadow passed over the observer. Observation showed that no such change was detected at Guelma. Any resultant polarisation would in this explanation depend also on dissymmetry in configuration of the contributing sources of illumination.

I refrain from dwelling upon some of the apparent difficulties arising in an acceptance of the idea that light pressure may be the agency by which just those particles of dust that are most active in scattering polarised light are driven out into streamers. It would appear that the particles most actively driven outwards would be those whose diameter was about one-third of the wave-length of the scattered polarised light. To adopt the view that they were driven out by the radiation pressure due to radiation of greater wave-length—let us say, ultra red—would mean that we are ready to accept the idea that the active pressure was connected with radiation known to be considerably feebler than the maximum components in the solar radiation. The particles driven out by the maximum components are already too big to scatter much polarised light, unless they simultaneously scatter unpolarised light in far larger quantities than there is evidence of in the photographic records. But it is unprofitable to try and solve what is essentially a quantitative problem by qualitative methods. I hope to revert to the subject later.

Solar Parallax Papers, No. 4. *The Magnitude Equation in Right Ascension of the Etoiles de Repère.* By Arthur R. Hinks, M.A.

1. The *étoiles de repère* for the reduction of the *Eros* plates were observed on the meridian at a large number of observatories, and the results were published in Paris Circulars Nos. 8 and 9.

M. Loewy published no definite catalogue of the places to be adopted as standard, preferring to leave to each observer the formation of a system for himself, at his own discretion as to the system of weights for the various observatories, and the allowance, if any, to be made for magnitude equation. As a result of this decision the published photographic places of *Eros* and the comparison stars are referred to a number of systems. The places adopted by M. Loewy for the reduction of the Paris photographs have been used also at Algiers, and in the reduction of the Catania plates at Paris. We will call this system L.

2. After a considerable part of the photographic reductions were completed, Professor Tucker published in Paris Circular No. 11 a system of places derived from a discussion of all the

meridian circle results, which he proposed for definitive adoption. He took no account of magnitude equation in the formation of this system, but published later (*Lick Observatory Bulletin*, No. 72) some reasons for thinking that the first part was free from magnitude equation, the second affected by an equation of $0^s.012$ per magnitude. We will call this system T.

In a letter to *The Observatory* (1905 July) the writer gave brief reasons for believing that the conclusion with regard to the first part was incorrect.

3. More recently Dr. Fritz Cohn has published in *Astronomische Nachrichten*, 4059–60 (1905 December) a second fundamental system, derived from the same material as Professor Tucker's, with considerable additions, but reduced to a Königsberg system of right ascensions made with the Repsold clockwork transit micrometer. Dr. Cohn claims that these observations are necessarily free from magnitude equation, and that by his reductions he has freed the other series also from its effects. We will call this system C.

4. The position at the present time is therefore this: Of the photographic observations already published Paris, Algiers, and Catania are based on system L; Toulouse on a system differing little from it; Bordeaux, San Fernando, and Northfield have used each an independent system.

Of the unpublished observations communicated for use in this investigation by the kindness of the Astronomer Royal, Dr. Backlund, and Professor Donner, the Greenwich results are referred to system L, the Pulkowa to system T, and the Helsingfors to an independent system.

5. Before the observations of the planet can be used for a discussion of the Solar Parallax and the mass of the Moon they all must be referred to one system. It has become now of immediate importance to inquire whether either system T (to which at present only the Pulkowa results are reduced) or system C (to which no photographic observations are as yet reduced) possesses advantages sufficient to warrant a reduction to it of all the observations; whether it would, on the contrary, be better to reduce all outstanding series to system L, on which very much is already founded; or whether still another fundamental system should be made from a photographic revision of one of these systems.

The present paper presents as a contribution to this inquiry the results of a determination of the magnitude equation in systems L, T, and C, derived by comparison with the deduced photographic places.

6. There are good reasons for believing that the most complete final test of freedom from magnitude equation in a series of meridian places is comparison with the results of a photographic revision of those places.*

* See papers on the magnitude equation in A. G. Zone Catalogues by the writer, *M.N.* lvii. 473 (1897 April), and by Professor Turner, *M.N.* lx. 3 (1899 November) and lxii. 3 (1901 November).

Provided that the magnitudes of the standard stars are fairly well distributed, the deduced photographic places of those stars are on the whole free from magnitude equation; at least none is caused by the existence of magnitude equation in the adopted standard places. Hence, if we can assure ourselves that the photographic processes have introduced no magnitude equation on their own account, we may use the photographic results to determine the magnitude equation of the visual.

7. The mean photographic places of the *étoiles de repère* are found in Paris Circulars Nos. 10 and 11 (Table I. for each observatory). Each series has been compared with Paris, with the following results:—

Table I.

Paris minus Other Observatories, Photographic R.A.

	Magnitudes.							
	−6·2	6·3–6·9	7·0–7·4	7·5–7·9	8·0–8·4	8·5–8·8	8·9–9·2	9·3–.
				Paris – Algiers.				
List I.	(5)+41	(6)+31	(15)+23	(27)+21	(53)+6	(64)−1	(43)−23	(11)−24
List II.	(5)+51	(7)+37	(8)+11	(17)− 3	(18)−6	(24)−9	(6)−19	...
Mean	(5)+46	(13)+34	(23)+19	(44)+12	(71)+3	(88)−3	(43)−23	(11)−24
				Paris – Bordeaux.				
List I.	(2)−17	...	(7)− 7	(12)− 2	(24)+10	(41)+ 7	(24)+ 2	(9)− 1
List II.	(2)+22	(4)−26	(4)−10	(6)− 1	(13)+ 1	(15)− 4	(3)+11	...
Mean	(4)+ 3	(4)−26	(11)− 8	(18)− 2	(37)+ 7	(56)+ 4	(27)+ 3	(9)− 1
				Paris – Catania.				
List I.	(3)+11	(2)−16	(9)+ 3	(21)+11	(39)+ 7	(43)+ 3	(31)+11	(8)− 4
List II.	(4)+22	(7)+16	(5)−15	(12)+ 8	(15) 0	(16)+ 5	(3)−13	...
Mean	(7)+17	(9)+ 9	(14)− 3	(33)+10	(54)+ 5	(59)+ 3	(34)+ 9	(8)− 4
				Paris – Greenwich.				
List I.	(3)−16	(5)− 2	(14) 0	(20)+ 3	(47)+ 2	(60) 0	(35)− 3	(8)+ 1
List II.	(3)+11	(4)− 2	(8)−10	(12)+ 1	(16)+ 3	(16)− 5	(3)− 1	...
Mean	(6)− 3	(9)− 2	(22)− 3	(32)+ 2	(63)+ 2	(76)− 1	(38)− 3	(8)+ 1
				Paris – Helsingfors.				
List I.	(3)+ 8	(4)+38	(9)+19	(15)+22	(22)+11	(38)+11	(20)+ 5	(10)+25
List II.	(5)+12	(3)+ 5	(8)+13	(12)+ 4	(16)+ 8	(18)− 9	(3)−27	...
Mean	(8)+11	(7)+24	(17)+16	(27)+14	(38)+10	(56)+ 4	(23)+ 2	(10)+25
				Paris – Northfield.				
List I.	(3)− 3	(5) 0	(12)+26	(19)+ 8	(33)+ 5	(46)+ 5	(33) 0	(7) 0
List II.	(3)+14	(1)+ 2	(2)+ 7	(5)+ 2	(9) 0	(8)− 8	(1)−17	...
Mean	(6)+ 5	(6)+ 1	(14)+24	(24)+ 7	(42)+ 4	(54)+ 4	(34)− 1	(7) 0

Paris – San Fernando

	Magnitudes. −6·2	6·3–6·9	7·0–7·4	7·5–7·9	8·0–8·4	8·5–8·8	8·9–9·2	9·3–.
List I.	(5)+12	(6)+14	(15)+17	(27)+16	(53)+15	(66)+10	(44)− 1	(13)−11
List II.	(5)+15	(7)+ 9	(8)− 6	(17)+ 8	(19)+ 1	(24)− 3	(3)−12	...
Mean	(10)+13	(13)+11	(23)+ 9	(44)+13	(72)+11	(90)+ 7	(47)− 2	(13)−11

Paris – Toulouse.

	−6·2	6·3–6·9	7·0–7·4	7·5–7·9	8·0–8·4	8·5–8·8	8·9–9·2	9·3–.
List I.	(5)−29	(6)+ 3	(15)+ 4	(27)− 3	(53)+10	(66)+ 3	(44)+ 3	(13)+ 4
List II.	(3)+17	(5)−25	(7)− 5	(11)+ 2	(18)− 5	(17)+ 6	(3)− 6	...
Mean	(8)−12	(11)−10	(22)+ 1	(38)− 2	(71)+ 6	(83)+ 4	(47)+ 3	(13)+ 4

The unit is $0^{s}\cdot001$.

The number of separate results contributing to each mean difference is given in brackets before it.

The magnitudes are according to Tucker.

8. The comparison with Algiers shows very clearly the now well known but still unexplained systematic error, depending at any rate partly upon magnitude, which affects the whole series from that observatory. It may, perhaps, be called for convenience "objective magnitude equation." Owing to the existence of this error no use can be made of the Algiers results in this paper.

The comparison with San Fernando shows small traces of a magnitude equation which may probably be due to the fact that these plates were not reversed during measurement.

With these exceptions there is little evidence of relative magnitude equation between the different series of photographic results. And it is hard to suggest any reason why all should be affected by a similar absolute magnitude equation. We may conclude that there is in general no sensible magnitude equation in the photographic right ascensions.

9. We may, therefore, deduce the magnitude equation in system T by a similar series of comparisons. The results are given in Table II.

Table II.

System T minus Photographic R.A.

T – Bordeaux.

	Magnitudes. −6·2.	6·3–6·9.	7·0–7·4.	7·5–7·9.	8·0–8·4.	8·5–8·8.	8·9–9·2.	9·3–.
List I.	(2)−25	...	(7)−38	(12)−19	(24)− 4	(41)+ 3	(24)+12	(9)+ 7
List II.	(2)−22	(4)−41	(4)−24	(6)− 2	(13)+ 4	(15)+ 1	(3)+40	...

T – Catania.

	−6·2.	6·3–6·9.	7·0–7·4.	7·5–7·9.	8·0–8·4.	8·5–8·8.	8·9–9·2.	9·3–.
List I.	(5)−45	(2)−30	(13)−23	(25)−12	(44)− 2	(51)+ 3	(38)+17	(9)− 2
List II.	(4)−12	(7)+ 5	(6)−31	(12)+ 4	(15)+ 1	(16)+12	(3)+15	...

	Magnitudes.							
	−6·2	6·3−6·9	7·0−7·4	7·5−7·9	8·0−8·4	8·5−8·8	8·9−9·2	9·3−.
				T – Greenwich.				
List I.	(4) − 19	(5) − 18	(18) − 26	(22) − 18	(49) − 6	(60) + 1	(38) + 11	(8) + 12
List II.	(3) − 3	(2) − 35	(11) − 23	(12) − 3	(16) + 4	(16) + 5	(3) + 29	...
				T – Helsingfors.				
List I.	(4) − 29	(4) + 23	(12) − 4	(17) + 3	(26) + 8	(39) + 11	(23) + 14	(10) + 34
List II.	(5) − 18	(3) − 15	(8) + 3	(12) + 2	(16) + 5	(19) + 3	(3) − 5	...
				T – Northfield.				
List I.	(5) − 12	(5) − 16	(16) + 3	(25) − 2	(36) + 1	(47) + 7	(35) + 11	(8) + 11
List II.	(3) − 12	(1) − 21	(2) − 14	(7) 0	(9) + 1	(8) + 1	(1) + 3	...
				T – Paris.				
List I.	(5) − 24	(6) − 21	(15) − 26	(27) − 13	(53) − 10	(66) 0	(44) + 11	(13) + 14
List II.	(5) − 26	(7) − 21	(8) − 12	(17) − 5	(19) − 1	(24) + 4	(3) + 28	...
				T – San Fernando.				
List I.	(7) − 21	(7) − 10	(20) − 7	(35) − 1	(58) + 5	(77) + 7	(55) + 10	(14) + 3
List II.	(5) − 11	(7) − 12	(9) − 19	(17) + 3	(19) + 1	(24) + 2	(3) + 16	...
				T – Toulouse.				
List I.	(7) − 66	(7) − 21	(20) − 18	(35) − 17	(57) − 1	(77) + 4	(55) + 13	(14) + 17
List II.	(3) − 20	(5) − 50	(7) − 16	(11) + 2	(18) − 5	(17) + 13	(3) + 23	...

The magnitudes are according to Tucker.

10. The results are somewhat irregular, especially for List II. But all agree in showing that system T has a considerable magnitude equation; that it is nearly the same in the two lists; and that it amounts to about $+0^{s}{\cdot}015$ per magnitude, the plus sign indicating that the right ascensions of faint stars are too great, or that they are observed relatively late.

11. There is some difficulty in determining the numerical value of the magnitude equation, because there are relatively few stars in the brighter groups, and accidental errors there affect the means disproportionately. Moreover it is fairly certain that the magnitude equation is not a linear function of the magnitude, even down to $9^{m}{\cdot}0$; but there is not sufficient material to show its true form.

All the numerical values given in this paper have been obtained by plotting the tabular results, and finding the general slope of the curve by laying a ruler on it, having regard to the numbers of stars which contribute to the different parts.

12. A similar comparison between Systems L and T shows that L has a magnitude equation in list I. about $+0^s{\cdot}005$ greater than that of T, thus confirming the result noticed by Professor Turner (*Nature*, 1904 December 15), and referred to by Professor Tucker (*L.O. Bulletin*, No. 72, last paragraph). For list II. there is practically no such difference.

13. Very similar results are found for the independent systems adopted at Bordeaux, Northfield, and Helsingfors. The magnitude equation between System T and San Fernando is of the same order, but is apparently not linear.

It follows that the published photographic results are based upon adopted systems which, though differing systematically, have nearly the same magnitude equation, about $+0^s{\cdot}020$ for list I. and $+0^s{\cdot}015$ for list II.

14. The comparison between System C and the photographic places from each observatory was made in the same way, and the results are given in Table III.

Table III.

System C minus Photographic R.A.

	Magnitudes.							
	−6·2.	6·3−6·9.	7·0−7·4.	7·5−7·9.	8·0−8·4.	8·5−8·8.	8·9−9·2	9·3−.
				C − Bordeaux.				
List I.	(2) −62	(4) −53	(4) −46	(12) −59	(29) −52	(45) −52	(30) −55	(10) −75
List II.	(3) −48	(1) 50	(4) −54	(11) −36	(13) −31	(15) −41	(6) −31	...
				C − Catania.				
List I.	(4) −54	(10) −70	(6) −73	(24) −48	(45) −48	(65) −53	(37) −55	(9) −82
List II.	(6) −16	(4) −32	(6) −38	(16) −35	(18) −26	(21) −42	(10) −41	...
				C − Greenwich.				
List I.	(6) −36	(11) −47	(7) −48	(20) −48	(53) −53	(70) −54	(38) −58	(9) −51
List II.	(5) −24	(2) −29	(8) −40	(19) −44	(25) −36	(19) −36	(10) −40	...
				C − Helsingfors.				
List I.	(5) −23	(7) − 7	(5) −25	(17) −27	(31) −39	(38) −42	(24) −48	(11) −42
List II.	(4) −24	(5) −23	(3) −36	(15) −21	(17) −40	(14) −45	(8) −46	...
				C − Northfield.				
List I.	(6) −29	(10) −27	(8) −31	(23) −35	(42) −49	(51) −47	(29) −61	(10) −45
List II.	(4) −27	(2) −38	(1) −52	(10) −29	(15) −41	(12) −44	(8) −37	...
				C − Paris.				
List I.	(5) −50	(13) −36	(8) −43	(23) −46	(59) −52	(78) −57	(46) −61	(14) −67
List II.	(8) −39	(6) −41	(7) −41	(27) −37	(30) −42	(28) −42	(14) −41	...

C − San Fernando.

	Magnitudes. −6·2	6·3−6·9	7·0−7·4	7·5−7·9	8·0−8·4	8·5−8·8	8·9−9·2	9·3−.
List I.	(9)−40	(17)−35	(11)−37	(34)−38	(65)−41	(95)−50	(57)−61	(14)−75
List II.	(8)−27	(6)−44	(9)−28	(27)−34	(30)−36	(32)−40	(13)−47	−

C − Toulouse.

	−6·2	6·3−6·9	7·0−7·4	7·5−7·9	8·0−8·4	8·5−8·8	8·9−9·2	9·3−.
List I.	(7)−64	(16)−52	(10)−54	(33)−54	(62)−44	(92)−54	(55)−57	(14)−65
List II.	(5)−44	(5)−34	(5)−44	(22)−42	(25)−39	(25)−44	(12)−41	...

The magnitudes are according to Cohn.

Contrary to expectation, it appeared that the clockwork micrometer system for list I. showed a considerable magnitude equation, of sign opposite to that of system T, faint stars being observed early.

A result so unfavourable to the hopes which have been centred in the new method of meridian observing demanded close examination.

15. In the first place a new comparison was made with a provisional system of mean photographic right ascensions, formed by taking a simple mean of the results published by the eight observatories. The means were unweighted, since weighting would have introduced in an irregular manner the systematic differences in zero of the different series, which for our present purpose do no damage to the simple means, so long as each list is fairly completely observed at each observatory.

The results of this new comparison are, with the same magnitude groups as before :—

Table IV.

System T − Mean Photographic R.A.

	−6·2	6·3−6·9	7·0−7·4	7·5−7·9	8·0−8·4	8·5−8·8	8·9−9·2	9·3−.
List I.	(9)−34	(16)−26	(11)−13	(34)− 8	(65)− 2	(96)+ 4	(57)+12	(14)+14
List II.	(8)−19	(6)−17	(9)−20	(28)− 4	(30) 0	(32)− 5	(15)+15	...

System C − Mean Photographic R.A.

	−6·2	6·3−6·9	7·0−7·4	7·5−7·9	8·0−8·4	8·5−8·8	8·9−9·2	9·3−.
List I.	(9)−45	(16)−43	(11)−44	(34)−47	(65)−47	(96)−52	(57)−60	(14)−60
List II.	(8)−28	(6)−35	(9)−39	(28)−36	(30)−39	(32)−44	(15)−42	...

System C − System T.

	−6·2	6·3−6·9	7·0−7·4	7·5−7·9	8·0−8·4	8·5−8·8	8·9−9·2	9·3−.
List I.	(9)−11	(16)−18	(11)−32	(34)−39	(65)−45	(96)−56	(57)−72	(14)−74
List II.	(8)− 9	(6)−18	(9)−19	(28)−33	(30)−38	(32)−38	(15)−57	...

The magnitude equation in system C for list I. is confirmed.

16. We must now introduce a distinction which has so far been neglected. List I. covers a range of declination from $+55°$ to $+37°$; list II. from $+39°$ to $+11°$. There seems to be no

a priori reason why magnitude equation should be independent of declination—rather the reverse—but there was the fact that the general magnitude equation of system T for lists I. and II. came out almost the same; and further, it was shown by Dr. Cohn that the differences between his final system C and his clockwork micrometer results are also independent of declination (*loc. cit.* p. 45).

But in searching for a reason why system C should have a magnitude equation for list I., and not for list II., the difference of declination suggested itself as a possible cause.

The differences which were combined to form the preceding table were therefore rearranged into three groups.

Group I. corresponds approximately to the portion of list I. north of Decl. $+49°$; these stars belong to that portion of the track of the planet pursued from 1900 October 10 to December 6.

Group II. comprises the rest of list I. between Decl. $+49°$ and $+39°$, covering the periods 1900 September 19–October 10, and December 6–29.

Group III. comprises the first part of list II. between Decl. $+38°$ and $+28°$, covering 1900 December 29 to 1901 January 25.

The mean results are as follows:—

Table V.

System T – Mean Photographic R.A.

Group I.	(3)−48	(7)−15	(5)−11	(15)− 6	(36)− 2	(52)− 1	(29)+ 8	(12)+14
Group II.	(6)−27	(9)−34	(6)−13	(19)− 9	(29)− 2	(44)+10	(28)+17	(2)+13
Group III.	(8)−19	(6)−17	(9)−20	(28)− 4	(30) 0	(32)− 5	(15)+15	...

System C – Mean Photographic R.A.

Group I.	(3)−58	(7)−29	(5)−37	(15)−37	(36)−42	(52)−52	(29)−62	(12)−61
Group II.	(6)−39	(9)−54	(6)−50	(19)−55	(29)−53	(44)−52	(28)−59	(2)−58
Group III.	(8)−28	(6)−35	(9)−39	(28)−36	(30)−39	(32)−44	(15)−42	...

A graphical determination of the magnitude equation gave

	System T.	System C.
	s	s
Group I.	+0·010	−0·017
Group II.	+0·016	−0·002
Group III.	+0·008	−0·002

The magnitude equation in T is irregular, but not apparently related to the declination; that of C appears strongly in the group of highest declination, scarcely at all in the others.

17. One can scarcely conclude that it really depends on the declination, since the difference of declination between groups I. and II. is not very great. But it appears certain that in group I.,

covering the period between October 10 and December 6, the system C has a magnitude equation larger than the average magnitude equation of system T, of the opposite sign. And the period in question is precisely the most important part of the whole, including opposition (October 31) and by far the greater part of the complete series east and west of the meridian.

To test this result further the differences were broken up into other groups, of which two covered between them a little more than the extent of group I.

Group A covered from October 10 to November 11, or roughly, from Decl. $+48°$ up to Decl. $+55°$.

Group B covered from November 11 to December 11; or, roughly from Decl. $+55°$ down the other side of the loop which the planet described as far as $+47°$.

System C – Mean Photographic R.A.

Group A	(1) −64	(4) −32	(3) −38	(7) −35	(21) −48	(32) −54	(21) −64	(4) −75
Group B	(3) −50	(4) −27	(2) −37	(10) −37	(17) −35	(23) −48	(11) −55	(14) −60

The magnitude equation is somewhat more strongly shown in group A than in B, which is some evidence against its intimate connection with declination.

18. As a final test the differences C minus Phot. R.A. were taken out respectively for each observatory and grouped as above. The same result came out again. With considerable variations in detail all showed more or less clearly that System C has a magnitude equation in the part covered by group I., and that it is somewhat more pronounced in the first half of that group than in the second.

19. Before accepting as final the conclusion that System C is affected in large part by a magnitude equation as great as that of System T, but of opposite sign, we must reconsider from every point of view our original proposition, that photographic places should show no magnitude equation on the mean of a long series.

Guiding error may produce photographic magnitude equation on individual plates, but we can hardly suppose it persistent with the same sign for six weeks at eight observatories.

Objective error may make the whole results of one observatory abnormal, but can hardly be supposed to exist of the same sign in eight telescopes for six weeks and then disappear.

For the same reason personality in measurement is excluded from the possibilities, even if it had not already been eliminated by reversal, except in one case.

20. There remains for consideration one qualification to our original proposition—the words, "provided that the magnitudes of the standard stars are fairly well distributed." Is it possible that there is anything so perverse in the distribution of magnitudes in the present case that the photographic methods break

down? A thorough examination of this point has been made, and the answer is decidedly in the negative.

The results of a single plate give the *slope* of the magnitude-equation curve; the zero line depends on the mean magnitude of stars on the plate. If the magnitude-equation of a system is uniform each plate should give the same slope, but each may have a different zero. A rigorous treatment of this problem would require the determination of the slope from each plate separately, and the deduction of a mean slope. In the present case this was impracticable because, unfortunately, the concluded results from each plate have not been published separately.

It is not hard to construct an arrangement of magnitudes along the path of the planet so systematically peculiar that the method followed in this paper would give a false result. The following experiment was therefore made: It was supposed that a whole series of meridian places was affected by a uniform magnitude-equation of $0^s.017$ per magnitude, and that the stars were distributed as in the actual system. By a method which is obvious, but tedious to explain, it was found that the magnitude-equation which would be derived from the different blocks of this system would be practically identical in all, viz. that originally introduced. There is, therefore, no peculiarity in the distribution of magnitudes which can affect the result we have obtained.

21. The method withstands all the tests which have been applied to it; but it gives results which are somewhat rough, because of the accidental errors in the standard systems, apart from the systematic magnitude-equation, and because of the accidental errors in the photographic places, which may become rather large for the brighter stars. Is it possible that accidental errors have combined to produce our result?

This question has been examined by a laborious method which can be but briefly described here. The stars which would fall on a series of plates taken on centres every 2° along the path of the planet have been taken out in the usual magnitude groups for each centre and the photographic places compared with Systems T and C. The mean difference for a given magnitude group was plotted for each centre, and these points were connected by lines of a different colour for each group. For example, the group 8·0–8·4 was represented by a green line, and 8·5–8·8 by a blue. If the green line runs parallel to the blue the magnitude-equation is consistent; if the lines of different colours cross, it is not consistent.

22. First a diagram was drawn for System C—mean photographic R.A. Throughout the parts of the curves belonging to October and November the magnitude-equation was shown roughly but fairly consistently. The same thing was done for C minus Paris, Greenwich, and Toulouse, separately. The results were rougher, but the same effect could be traced.

Finally, similar curves were drawn for System T—mean photographic R.A., and the results were decidedly more consistent than for C.

23. From these investigations, which have been tested and varied in every way that can be thought of, the following results emerge:—

System T has a fairly uniform magnitude-equation of about $+0^s{\cdot}015$ per magnitude throughout list I. and the first half of list II.; for the second half there is little material.

System L and the independent adopted systems have a magnitude-equation of about $+0^s{\cdot}020$ for list I. and $+0^s{\cdot}015$ for list II.

System C has a magnitude-equation of about $-0^s{\cdot}017$ for about half list I. and of $-0^s{\cdot}002$ for the remainder and for list II.

It seems to me, therefore, that so far as magnitude-equation is concerned System T is little better than System L, while System C is worse, because it changes so suddenly. From this point of view there would be little advantage in adopting either T or C as the standard system for the reduction of all the photographs.

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Cambridge Observatory:
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On some Points connected with the Determination of Orbits.

By H. C. Plummer, M.A.

1. The difference between the circular measure and the sine of an angle is an expression which occurs in several of the most important formulæ relating to elliptic motion. When the angle is large there is no difficulty in calculating this difference accurately, but when it is small ordinary logarithmic tables will not give the required accuracy without the help of some special device. Hence auxiliary tables have been published in a variety of forms, according to the purpose for which they are designed. It is possible to restrict the compass of such tables by making them merely supplementary to the ordinary logarithms by the use of some artifice. Of this nature is Tietjen's* formula, which may be expressed in the form

$$\epsilon - \sin\epsilon = \tfrac{4}{3}\,B \sin^3 \tfrac{1}{2}\epsilon\,(\sec\tfrac{1}{4}\epsilon)^{2\cdot4} \quad \dots \quad \dots \quad (1)$$

* *A.N.* 1463; also Watson's *Theoretical Astronomy*, p. 343.

for which a very small table, giving log B as far as $\epsilon = 60^\circ$, is necessary. But the use of any special table can be avoided. Thus I have pointed out elsewhere * that the function

$$\tfrac{1}{6}\,\epsilon^3 / (\sec \tfrac{1}{12}\,\epsilon)^{14 \cdot 4} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

is a remarkably close approximation to the value of $\epsilon - \sin \epsilon$; indeed, over the range of ϵ from 0° to 70° the difference between the logarithms of the two expressions does not exceed 2 in the seventh place. A greater error may be caused by the occurrence of the power 14·4. It may be noted that if ϵ is less than 36° the logarithm of the required secant can be obtained from Schrön's tables (as the difference between S and T) to eight places. Within this range at least the approximation may be considered practically perfect.

2. A function of such frequent occurrence that it has been made the subject of special tables is

$$Q(\epsilon) = \tfrac{3}{4}(\epsilon - \sin \epsilon)/\sin^3 \tfrac{1}{2}\epsilon.$$

This can be expressed by Tietjen's formula thus:

$$Q(\epsilon) = B(\sec \tfrac{1}{4}\epsilon)^{2 \cdot 4} \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

or by using the approximate expression (2)

$$Q(\epsilon) = (\tfrac{1}{2}\epsilon / \sin \tfrac{1}{2}\epsilon)^3 (\sec \tfrac{1}{12}\epsilon)^{-14 \cdot 4} \quad \ldots \quad \ldots \quad (4)$$

provided $\epsilon < 70^\circ$. Now the nature of the function $Q(\epsilon)$, which is unity when $\epsilon = 0^\circ$, suggests that it may be represented very approximately by the form $(\sec b\epsilon)^a$, a and b being two constants so chosen as to give the best possible result. For practical purposes, however, b must be a very simple factor. This limitation precludes a quite satisfactory approximation: no great improvement can be made on the trigonometrical factor in (3). But the case is different if we seek to represent Q not by a single term $(\sec b\epsilon)^a$, but by a product of two such terms. This is shown by considering the logarithmic expansions of the functions involved.

3. In the first place, if μ is the modulus of common logarithms,

$$\log(\epsilon - \sin \epsilon) - 3 \log \epsilon + \log 6$$
$$= \mu\left[-\tfrac{1}{20}\epsilon^2 - \tfrac{1}{16800}\epsilon^4 + \tfrac{1}{756000}\epsilon^6 + \tfrac{89}{3104640000}\epsilon^8 + \ldots\right] \quad (5)$$

We have also

$$\log \sin x = \log x - \mu \Sigma\, B_{2i-1} \frac{2^{2i}}{2i \cdot \underline{|2i}}\, x^{2i} \quad \ldots \quad \ldots \quad (6)$$

$$\log \sec x = \mu \Sigma\, B_{2i-1} \frac{2^{2i}(2^{2i} - 1)}{2i\, \underline{|2i}}\, x^{2i} \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

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* *A.N* 3883

where B_1, B_3, ... are Bernoulli's numbers, of which the first four are $\frac{1}{6}$, $\frac{1}{30}$, $\frac{1}{42}$ and $\frac{1}{30}$. By means of (5) and (6) we find

$$\log Q(\epsilon)=\mu\left[\tfrac{3}{40}\epsilon^2+\tfrac{11}{11200}\epsilon^4+\tfrac{1}{560000}\epsilon^6+\tfrac{701}{2069760000}\epsilon^8+\ldots\right] \quad (8)$$

The object is now to combine two series of the form (7) in such a way as to reproduce the first terms of (8). Theoretically an attempt might be made to obtain the first four terms; but if simple multiples of ϵ only are admitted, a less perfect agreement must suffice. It is indeed remarkable enough that with the multiples $\frac{1}{4}$ and $\frac{1}{6}$ of ϵ three terms can be made to coincide. Thus the application of (7) gives

$$\begin{aligned}&\tfrac{24576}{7000}\log\sec\tfrac{1}{4}\epsilon-\tfrac{17496}{7000}\log\sec\tfrac{1}{6}\epsilon\\ &=\mu\left[\tfrac{3}{40}\epsilon^2+\tfrac{11}{11200}\epsilon^4+\tfrac{1}{560000}\epsilon^6+\tfrac{17}{48384000}\epsilon^8+\ldots\quad\right]\\ &=\log Q(\epsilon)-\tfrac{59}{4656960000}\mu\epsilon^8-\ldots\end{aligned}$$

The outstanding part of the fourth term amounts to 1 in the seventh place when $\epsilon=82°$ and the succeeding terms are still smaller. Practically throughout the first quadrant we may write

$$\begin{aligned}\log Q(\epsilon)&=\tfrac{24576}{7000}\log\sec\tfrac{1}{4}\epsilon-\tfrac{17496}{7000}\log\sec\tfrac{1}{6}\epsilon\\ &=[0{\cdot}5454132]\log\sec\tfrac{1}{4}\epsilon-[0{\cdot}3978408]\log\sec\tfrac{1}{6}\epsilon\ \ldots\quad(9)\end{aligned}$$

The range is greater than is actually necessary, since Q can be calculated directly when ϵ has a fairly large value.

4. As an example of the use of such formulæ let us consider the method of Gauss for determining an orbit when two heliocentric positions are known. This involves the solution of the equations

$$y^2=m/(l+\sin^2\tfrac{1}{2}g)\quad\ldots\quad\ldots\quad\ldots\quad\ldots\quad(10)$$

$$y^3-y^2=m(2g-\sin 2g)/\sin^3 g=\tfrac{4}{3}mQ(2g)\ \ldots\quad\ldots\quad(11)$$

where y is the ratio of the sector to the triangle, $2g$ is the difference of the eccentric anomalies, and l and m are given quantities. These equations can be solved by trial without using special tables such as have been given by Gauss. The natural course is to choose an approximate value of $2g$ (in the absence of more precise knowledge, $2f$, the difference of the true anomalies, may be taken) and to deduce y by means of (11). Then (10) will give an improved value of g, with which the process can be repeated.

Let $y=1/c\sinh\alpha$. Then, by (11),

$$4mQc^3\sinh^3\alpha+3c\sinh\alpha-3=0,$$

which can be compared with

$$4\sinh^3\alpha+3\sinh\alpha-\sinh 3\alpha=0,$$

giving $$mQc^2 = 1, \quad c \sinh 3a = 3.$$

Now if
$$e^{3a} = \cot \tfrac{1}{2}\beta, \quad e^{a} = \cot \tfrac{1}{2}\gamma$$
$$\sinh 3a = \cot \beta, \ \sinh a = \cot \gamma.$$

For (10) we may write
$$\sin^2 \tfrac{1}{2}g = l \tan^2 \delta, \ y^2 = m \cos^2 \delta / l.$$

Then the calculation from an assumed value of g to a better approximation is reduced to the following system of equations :—

$$\left.\begin{aligned} \cot \beta &= 3m^{\frac{1}{2}}Q^{\frac{1}{2}} \\ \tan^3 \tfrac{1}{2}\gamma &= \tan \tfrac{1}{2}\beta \\ \cos \delta &= l^{\frac{1}{2}}Q^{\frac{1}{2}} \tan \gamma \\ \sin \tfrac{1}{2}g &= l^{\frac{1}{2}} \tan \delta \\ y &= m^{\frac{1}{2}}l^{-\frac{1}{2}} \cos \delta \end{aligned}\right\} \quad \ldots \quad \ldots \quad (12)$$

with

the last step being made only after satisfactory values of g and δ are known.

5. The application of the method will be made clearer by a numerical example. The following * is chosen : $t'-t$, the interval of time, $=$ 100 days, $\log r = 0{\cdot}221\ 6050$, $\log r' = 0{\cdot}209\ 9050$, $2f$, the angle between the two radii, $= 44^\circ 25' 48''{\cdot}00$; whence

$$m = k^2(t'-t)^2/8 \cos^3 f (rr')^{\frac{3}{2}} = [9{\cdot}021\ 2961]$$
$$l = (r+r')/4 \cos f (rr')^{\frac{1}{2}} - \tfrac{1}{2} = [8{\cdot}603\ 5663]$$

The complete calculation by means of Bremiker's 6-figure logarithms is given below (see p. 495).

Now if, as in the given calculation, one assumed value x_1 leads to a closer approximation x_2, and x_2 similarly leads to x_3, the approximate correction to x_3 is

$$x - x_3 = (x_3 - x_2)^2 / \{(x_2 - x_1) - (x_3 - x_2)\} \quad \ldots \quad \ldots \quad (13)$$

which, applied to the successive values of $\tfrac{1}{2}g$, gives

$$\tfrac{1}{2}g - \tfrac{1}{2}g_3 = (63''{\cdot}8)^2 \div 3658'' = +1''{\cdot}11.$$

The calculation of y can now be completed thus :—

$\tfrac{1}{2}g$	$12^\circ\ 5'\ 18''{\cdot}1$	δ	$46^\circ\ 16'\ 6''{\cdot}2$
L. sin $\tfrac{1}{2}g$	9·321018	L. cos δ	9·839654
$\tfrac{1}{2}$ L. l	9·301783	$\tfrac{1}{2}$ L. m	9·510648
		$-\tfrac{1}{2}$ L. l	0·698217
L. tan δ	0·019235		
		L. y	0·048519

* For the same example worked by Gauss' special tables see Bauschinger's *Tafeln zur Theoretischen Astronomie*, p. 26.

Calculation referred to on p. 494.

$2g$	44° 25′ 48″·0	48° 25′ 23″·2	β	45° 9′ 20″·0	45° 1′ 56″·2
$\frac{1}{2}g$	11 6 27·0	12 6 20·8	$\frac{1}{2}\beta$	22 34 40·0	22 30 58·1
$\frac{1}{3}g$	7 24 18·0	8 4 13·9			
			L. tan $\frac{1}{2}\beta$	9·618890	9·617571
L. sec $\frac{1}{2}g$	0·008213	0·009766	L. tan $\frac{1}{2}\gamma$	9·872963	9·872524
L. sec $\frac{1}{3}g$	0·003637	0·004323			
			$\frac{1}{2}\gamma$	36° 44′ 13″·6	36° 42′ 33″·6
LL. sec $\frac{1}{2}g$	7·560743	7·635785	γ	73 28 27·2	73 25 7·2
const.	0·397841	0·397841			
L. (1)	7·958584	8·033626	L. tan γ	0·527678	0·526136
			$\frac{1}{2}$ L. l	9·301783	9·301783
LL. sec $\frac{1}{3}g$	7·914502	7·989717	$\frac{1}{2}$ L. Q	0·009872	0·011741
const.	0·545413	0·545413			
L. (2)	8·459915	8·535130	L. cos δ	9·839333	8·839660
(2)	0·028835	0·034287	δ	46° 18′ 32″·3	46° 16′ 3″·6
(1)	0·009090	0·010805			
			L. tan δ	0·019851	0·019224
L. Q	0·019745	0·023482	$\frac{1}{2}$ L. l	9·301783	9·301783
L. 9	0·954243	0·954243			
L. m	9·021296	9·021296	L. sin $\frac{1}{2}g$	9·321634	9·321007
sum	9·995284	9·999021	$\frac{1}{2}g$	12° 6′ 20″·8	12° 5′ 17″·0
L. cot β	9·997642	9·999511			

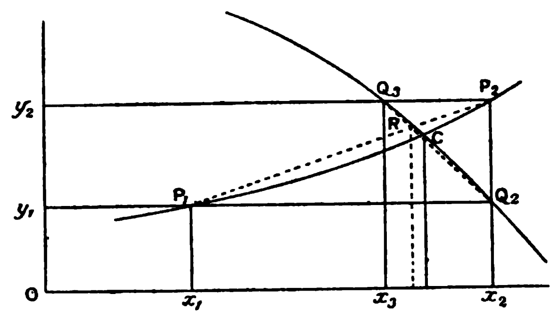
The value found by 7-figure logarithms and Gauss' tables is $\log y = 0{\cdot}0485191$. The accuracy of the result is naturally greater than can be expected in general from a 6-figure computation, but the above example is merely illustrative of the method, and a more accurate calculation is therefore unnecessary.

6. It may be remarked that a still rougher computation may be of use as a preliminary step. Thus 4-figure logarithms are enough to give $\frac{1}{2}g$ in this case with an error not greater than 1′. But for the effective application of (13) it is necessary to make the two successive calculations with nearly the same order of accuracy. This formula, which is quite general, can easily be proved on the assumption that only the first powers of the errors committed are of importance. The general problem is to solve the equations

$$y = p(x), \; y = q(x),$$

where p and q are functions which involve algebraic or transcendental forms, by assuming a value x_1 and deducing x_2, which in turn is made a starting-point to obtain x_3. The two equations

may be represented graphically by the curves P_1CP_2 and Q_2CQ_3, the coordinates of whose intersection C are to be found. The method may then be translated thus: (1) with the assumed abscissa x_1 find the ordinate y_1 of P_1, (2) with this ordinate find the abscissa x_2 of Q_2 on the second curve, (3) with the abscissa x_2 find the ordinate y_2 of P_2 on the first curve, (4) with the ordinate y_2 find the abscissa x_3 of Q_3 on the second curve. It is then clear that the meaning of the correction given by (13) is to give the point R in which the straight lines P_1P_2 and Q_2Q_3 intersect. This graphical representation shows clearly the general nature of the process, and suggests in an interesting way the conditions on which its effectiveness depends. These conditions involve the slope and curvature of the lines, and are well illustrated by the special problem discussed above.



7. The equations (10) and (11), which are due to Gauss, are closely related to Lambert's theorem for elliptic motion, which is expressed by the familiar equation

$$a^{-\frac{3}{2}}k(t'-t) = (\epsilon - \sin\epsilon) - (\delta - \sin\delta) \quad \ldots \quad \ldots \quad (14)$$

where

$$\sin^2 \tfrac{1}{2}\epsilon = \frac{r+r'+c}{4a}, \ \sin^2 \tfrac{1}{2}\delta = \frac{r+r'-c}{4a} \quad \ldots \quad \ldots \quad (15)$$

I have shown * that when the eccentricity is moderate and the interval between the observations is not unreasonably large, this system of equations is capable of a convenient solution and gives a practical method of determining the elements of an orbit. The usefulness of the theorem has been more generally recognised in cases of large (nearly parabolic) eccentricity. Now it is obvious that a direct calculation of $t'-t$ will not be accurate when the mean distance a is large and consequently ϵ and δ are small, especially if the chord c is also small in comparison with the radii. Hence Marth † has derived elaborate expansions in series and calculated extended tables from the results. The value of these tables is well known. Yet, though they are

* *M.N.* vol. lxiii. p. 147. † *A.N.* 1557–1560.

doubtless convenient, they are not indispensable. It seems worthy of notice that complete accuracy can be attained by the ordinary forms of calculation.

8. With any assumed value of a, ϵ and δ can be calculated by (15); moreover, the difference of these equations gives

$$\sin \tfrac{1}{2}(\epsilon-\delta)\sin \tfrac{1}{2}(\epsilon+\delta) = c/2a \quad \dots \quad \dots \quad \dots \quad (16)$$

whence the difference $\epsilon-\delta$ can also be calculated with all necessary accuracy. Now since

$$\begin{aligned} 2\sin \tfrac{1}{2}(\epsilon-\delta)-(\sin\epsilon-\sin\delta) &= 2\sin\tfrac{1}{2}(\epsilon-\delta)\{1-\cos\tfrac{1}{2}(\epsilon+\delta)\} \\ &= c/a \,.\, \tan\tfrac{1}{4}(\epsilon+\delta) \end{aligned}$$

the equation (14) can now be written

$$\begin{aligned} k(t'-t) &= a^{\frac{1}{2}}c\tan\tfrac{1}{4}(\epsilon+\delta) \\ &\quad + 2a^{\frac{3}{2}}\{\tfrac{1}{2}(\epsilon-\delta)-\sin\tfrac{1}{2}(\epsilon-\delta)\} \quad \dots \quad (17) \end{aligned}$$

We now have a sum of two *positive* terms, each of which can be calculated without difficulty. By (16) this becomes

$$k(t'-t) = a^{\frac{1}{2}}c\tan\tfrac{1}{4}(\epsilon+\delta)+\tfrac{1}{24}a^{-\frac{3}{2}}c^3\sin^{-3}\tfrac{1}{2}(\epsilon+\delta).\, \mathrm{A} \quad \dots \quad (18)$$

where

$$\mathrm{A} = 6\{\tfrac{1}{2}(\epsilon-\delta)-\sin\tfrac{1}{2}(\epsilon-\delta)\}/\sin^3\tfrac{1}{2}(\epsilon-\delta)$$

and tends to the value 1 when $\epsilon-\delta$ is small. It is always possible to calculate log A with the help of (2) or (9). Frequently the second term in (18) is small compared with the first term, and A is not required with great accuracy. An approximation which may be useful can be obtained by the method of § 3. This is

$$\log \mathrm{A} = 3{\cdot}6\log\sec\tfrac{1}{4}(\epsilon-\delta) \quad \dots \quad \dots \quad (19)$$

which exceeds the true value by 1 in the seventh place when $\epsilon-\delta=12°$, and will therefore in general be good enough in the case of an ellipse which is nearly parabolic.

9. It is of interest to notice the corresponding form of Euler's equation for parabolic motion. We have a infinite and $\delta=\epsilon=0$, but at the same time the finite limits

$$a\epsilon^2 = r+r'+c, \qquad a\delta^2 = r+r'-c.$$

Since now $\mathrm{A}=1$, (17) becomes

$$k(t'-t) = \tfrac{1}{4}c\mathrm{R}+\tfrac{1}{3}c^3/\mathrm{R}^3 \quad \dots \quad \dots \quad \dots \quad (20)$$

where

$$\mathrm{R} = (r+r'+c)^{\frac{1}{2}}+(r+r'-c)^{\frac{1}{2}}.$$

This, unlike the ordinary form, is suitable for the calculation of $t'-t$ however small c may be, although not so convenient as the trigonometrical transformation employed by Encke.*

* *Berl. Jahrbuch*, 1833, p. 268

10. The numerical application of (18) is in practice very simple and convenient. For example, let $r = 1.5$, $r' = 1.51$, and $c = 0.15$, and let us calculate the time-interval corresponding to these values * of a : 1.55, 10, 400 and infinity. We obtain the following results :—

a.	Period. Years.	$\frac{1}{2}\epsilon$. ° ′ ″	$\frac{1}{2}\delta$. ° ′ ″	$t'-t$. Days.
1.55	1.93	45 33 16.26	42 46 47.55	10.549300
10	31.6	16 19 26.55	15 30 33.49	7.865279
400	8000	2 32 49.630	2 25 23.236	7.570711
∞	∞	...	...	7.563420

In all these cases the second term on the right of (18), or (20) in the case of the parabola, could be calculated by 4-figure logarithms. Further, the value of log A was 0.0005 in the first case, and negligible for the other two elliptic orbits. The form (18) will always give accurate results, and the advantage which it offers becomes most conspicuous in those cases which have been considered to present the greatest difficulty.

University Observatory, Oxford :
1906 *June* 4.

Errors of Tabular Place of Jupiter, from Photographs taken with the Astrographic 13-*inch Refractor of the Royal Observatory, Greenwich.*

(*Communicated by the Astronomer-Royal.*)

In communicating the results of measures of photographs of the sixth and seventh satellites of *Jupiter* it was pointed out that in deducing the position angle and distance the error of the tabular place of *Jupiter* had been neglected.

To eliminate this error, and also that arising from any systematic error of the catalogues employed, a series of photographs of *Jupiter* was taken with the astrographic 13-inch refractor, with exposures only just long enough to give good measurable images of the known stars, *i.e.* 30^s.

In all ten photographs, taken between 1905 November 3 and 1906 February 15, have been selected and measured. Four images each of *Jupiter* and of about twelve stars were measured on each plate, the positions of the stars being derived from the *Astronomische Gesellschaft Catalogue* (Berlin zones). The deduced positions of *Jupiter* are thus affected by any systematic error of the catalogue and the error due to twenty-five years' unknown proper motion of the stars ; but, as the positions of the satellites, deduced in the same manner, are affected by the same errors, it

* For two methods of calculating $t'-t$ for the case $a = 10$ see Bauschinger's *Tafeln*, pp. 32, 33.

follows that this is the proper place of *Jupiter*, with which the places of the satellites should be compared.

The stars on the photographs were measured in the duplex astrographic micrometer, but, as the division errors of the microscope scales have not yet been determined, *Jupiter* was measured in the *Eros* micrometer. Corrections for division errors of the scale and of the réseau have been applied to the measures of *Jupiter*.

The tabular errors so obtained are given below, together with those obtained from fundamental observations made with the Transit Circle and with the Altazimuth.

Errors of Tabular Place (T − O)

Astrographic.					Transit Circle.				Altazimuth.			
1905.		Position of Telescope.	R.A.	Dec.	1905.		R.A.	Dec.	1905.		R.A.	Dec.
			s	″			s	″			s	″
Nov.	3	W	−·13	−0·2	Sept.	18	−·07	−0·5	Sept.	18	−·14	−1·5
	21	W	−·07	+0·8	Oct.	16	−·10	0·0	Oct.	19	−·01	+0·3
	23	W	−·05	+0·7		27	+·03	+0·7	Dec.	2	−·07	−0·2
	29	W	−·09	+0·8		31	−·18	...	1906. Jan.	5	−·19	−0·7
1906. Jan.	19	W	−·02	−0·1	Nov.	2	−·13	−0·7		8	−·07	−0·6
	19	E	−·03	−0·7		6	...	−2·2		10	−·03	−2·1
	23	E	−·04	−0·6		7	+·05	−0·6		24	−·07	−0·6
	29	E	+·01	−0·6		15	+·02	+1·4	Feb.	5	−·14	+0·3
Feb.	14	E	−·03	0·0		21	−·03	−0·1		9	−·02	−2·1
	15	W	−·03	−0·1		23	−·06	−0·5		20	−·11	+0·5
						24	−·07	+0·4		21	−·09	−0·8
						27	−·05	+0·3				
						29	−·02	−0·9				
					Dec.	2	+·03	+0·7				
						8	−·07	−1·2				
						9	−·04	0·0				
					1906. Jan.	5	−·08	−1·3				
Mean ...			−^{s}·048	0″·00			−^{s}·051	−0″·29			−^{s}·085	−0″·68

It should be noted that the photograph on November 3 is very unsatisfactory.

A correction of −″·36 for R−D has been applied to the declinations observed with the Transit Circle; of +″·48 to those with the Altazimuth on September 18 and October 19, and of −″·13 to the remainder.

Royal Observatory, Greenwich:
1906 *June* 7.

Results of Micrometer Measures of Double Stars made with the 28-inch Refractor at the Royal Observatory, Greenwich, in the year 1905.

(*Communicated by the Astronomer Royal.*)

The measures were made with a bifilar position-micrometer on the 28-inch refractor, focal length 28 feet. The power generally employed was 670. When bright stars were observed a blue glass shade was usually employed to diminish the light and irradiation. The observations were made in variously coloured fields or in a dark field with illuminated wires. The initials in the last column are those of the observers, viz.

L.	Mr. Lewis	H.F.	Mr. Furner.
W.B.	Mr. Bowyer	Bk.	M. Van Biesbroeck.

M. Van Biesbroeck, of Brussels, spent some time at the Observatory, studying the details of various departments. On nights when the definition was not sufficiently good for measuring stars in the ordinary working list the time was spent in measuring stars from a supplementary list made up of Struve stars which have been neglected, or which require periodical observation at intervals of ten years or so, and of miscellaneous stars in which the companion is very faint. As measures of such pairs are not of immediate interest a list only of the stars observed is given here, the publication of the measures, as well as of the individual results of the observations of the other stars, being reserved for the volume of *Greenwich Observations* for 1905.

In general the present list of measures is confined to stars of which the separation is under 4″, or which show orbital movement.

Stars in the Supplementary List observed in 1905.

Struve Stars.

Σ 1955	Σ 2137	Σ 2336	Σ 2655	Σ 2734	Σ 2931
1953	2140 AB	2327	2664	2736	2932
1963	2140 AC	2364	2679	2738	2941
1964	2188	2376	2680	2761	2946
1977	2201	2381	2686	2763	2992
1992	2202	2385	2691	2831	3014
2003	2213	2390	2688	2833	3018
2005 AC	2211	2396	2692	2848	3021
2008	2217	2424	2700	2852	3028
2032 AC	2224	2426	2702	2867	3039
2040	2228	2530	2708	2877	3042
2095	2232	2585	2709	2890	3044
2104	2233 AC	2618	2713	2897	3055
2109	2233 AD	2622 AB	2714	2898	3058
2110	2264	2622 AC	2715	2902	3097
2115	2269	2631	2718	2910	3132
2113	2295	2633	2722	2916 AB	3134
2142	2311	4263	2725	2916 AC	

Otto Struve Stars.

OΣ 225, 230, 362, and 535 AC

Hough Stars.

Ho, 204, 475, 609 AC, 609 AD, 609 AE, and 614.

Miscellaneous Stars.

Burnham 151 $\frac{AB}{2}$ C

G. A. 5.

B.D. + 21°·3994 AC

Micrometric Observations of Double Stars at the Royal Observatory, Greenwich.

Star's Name.		R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights	Mags.		Epoch 1905.	Obs.
		h m	° ′	°	″					
Σ 3060	...	0 1	72 29	118·9	3·50	1	8·7	8·7	·994	W.B.
Ho. 1	...	0 6	61 10	170·3	1·19	1	8·5	8·8	·909	L.
A.G. 56	...	0 12	68 47	133·9	2·25	3	8·9	9·4	·639	W.B
Ho. 305	...	0 33	65 19	193·2	5·91	2	8	11	·912	W.B.
Ho. 306	...	0 43	64 59	165·9	1·13	2	8·5	8·8	·529	W.B.
β 495	...	0 44	71 51	28·9	0·57	1	7·5	7·7	·887	W.B.
Σ 73	...	0 50	66 55	25·8	0·96	2	6·2	6·8	·912	W.B.
β 302	...	0 53	69 9	117·2	0·57	1	6·8	8·0	·887	W.B.
Ho. 310	...	1 20	61 1	356·7	1·57	1	9·0	9·2	·830	W.B.
Ho. 9	...	1 24	68 45	96·2	2·83	2	9	10	·912	W.B.
β 507	...	1 30	63 44	151·3	1·86	1	8·0	11·0	·917	W.B.
Ho. 311	...	1 46	65 48	185·7	0·49	1	7·0	7·2	·830	W.B.
Σ 194	...	1 54	65 39	276·1	0·97	3	8·0	8·3	·056	W.B.
				272·6	1·46	1	...		·049	L.
Ho. 11	...	1 54	56 13	141·9	4·85	1	9·0	9·4	·994	W.B.
Ho. 312	...	2 1	64 45	345·5	0·97	2	6·5	12·0	·044	L.
Σ 226	...	2 7	66 30	246·5	2·26	2	7·8	9·7	·039	L.
Hu. 424	...	2 8	66 44	335·4	1·56	3	9·0	11·0	·046	L.
Ho. 216	...	2 21	59 9	344·1	1·14	2	8·0	10·0	·030	L.
				338·3	0·95	1	...		·033	H.F.
Σ 269	...	2 21	60 34	324·7	1·93	1	7·5	9·8	·917	W.B.
Hu. 428	...	2 23	67 7	68·7	0·57	1	9·2	9·5	·011	L.
β 306	...	2 38	64 48	16·7	3·01	3	6·7	11·0	·027	L.
Hu. 430	...	2 38	69 26	188·2	0·77	1	8·5	12·8	·066	L.
Ait. 826	...	2 39	58 56	165·7	4·16	1	8·7	11·8	·066	L.
Σ 305	...	2 42	71 2	311·8	2·99	3	7·3	8·2	·038	W.B.
Ho. 217	...	2 43	55 54	276·2	2·87	1	8·5	10·7	·033	H.F.

Star's Name.	R.A. 1900. h m	N.P.D. 1900. ° ′	Position Angle. °	Distance. ″	No. of Nights.	Mags.	Epoch 1905.	Obs.
β 525 ...	2 53	68 47	139·4	0·50	1	7·5 7·5	·049	L.
Σ 333 ...	2 54	69 4	198·0	1·11	3	5·7 6·0	·047	W.B.
Ho. 318 ...	2 54	73 19	205·5	3·15	1	9·1 9·1	·994	W.B.
Σ 346 ...	2 58	65 8	89·0	0·39	1	6·0 6·0	·074	W.B.
β 1030 ...	3 4	68 39	143·4	0·45	2	8·4 8·4	·078	W.B.
Ho. 14 ...	3 28	62 2	24·6	2·07	1	8·2 8·7	·994	W.B.
β 533 ...	3 29	58 39	48·6	0·80	1	7·0 7·0	·066	L.
Ho. 504 ...	3 38	54 29	182·6	0·88	1	7·8 8·0	·112	W.B.
Ho. 324 ...	3 44	75 18	332·8	0·64	3	8·1 8·3	·127	W.B.
			339·3	0·72	1	...	·033	H.F.
Hu. 24 ...	3 52	78 48	267·1	0·81	1	8·5 11·3	033	H.F.
Hu. 25 ...	3 53	78 10	324·9	0·81	1	8·6 9·1	·033	H.F.
Hu. 27 ...	3 54	80 29	214·3	0·53	1	8·1 8·5	·033	H.F.
Hu. 28 ...	3 54	78 50	340·3	1·21	1	9·0 9·2	·033	H.F.
Σ 520 ...	4 12	67 27	113·8	0·61	3	8·0 8·0	·078	W.B.
Σ 535 ...	4 18	78 51	323·1	1·64	2	6·7 8·2	·077	W.B.
Ho. 15 ...	4 18	60 7	147·4	0·72	2	8·0 8·0	·167	W.B.
β 1186 ...	4 22	79 1	172·8	0·51	1	6·8 9·7	·151	H.F.
OΣ 86 ...	4 31	70 15	54·4	0·45	1	7·5 7·5	·044	W.B.
Σ 567 ...	4 31	70 43	320·9	1·86	2	8·5 9·0	·035	W.B.
Σ 572 ...	4 32	63 18	201·5	3·76	2	6·5 6·5	·035	W.B.
Ho. 333 ...	4 38	69 53	158·6	2·17	1	9·2 9·3	·994	W.B.
Ho. 17 AB	4 53	59 8	56·5	4·36	2	7·5 10·0	·049	W.B.
Ho. 222 ...	4 53	58 34	219·3	1·87	1	7·7 10·5	·049	L.
β 1238 ...	4 55	63 36	7·2	1·56	1	8·1 11·5	·022	L.
Ho. 225 ...	5 16	77 26	111·9	0·46	3	8·0 8·1	·164	W.B.
Ho. 226 ...	5 21	62 29	238·6	0·57	4	7·0 7·0	·155	W.B.
			238·4	0·81	1	...	·153	L.
Σ 749 ...	5 31	63 8	172·2	0·66	3	7·0 7·1	·034	W.B.
Hu. 38 ...	5 39	67 8	140·8	0·48	3	8·6 8·8	·148	W.B.
			141·9	0·56	1	...	·208	H.F.
B.D. +20°·1259	6 1	69 53	187·3	2·14	1	8·7 10·0	·022	L.
			192·0	1·27	1	...	·151	H.F.
Ho. 228 ...	6 1	77 31	271·2	2·47	2	8·0 11·0	·162	W.B.
B.D. +24°·1161	6 7	65 33	178·3	1·32	2	9·0 9·2	·056	W.B.
Ho. 24 ...	6 13	80 38	156·0	4·22	1	8·0 11·0	·225	H.F.
Ho. 230 ...	6 13	76 11	61·5	1·94	2	8·2 10·5	·162	W.B

Star's Name.	R.A. 1900. h m	N.P.D. 1900. ° ′	Position Angle. °	Distance. ″	No. of Nights.	Mags.	Epoch 1905	Obs.
Σ 888 AC ...	6 14	61 31	258·2	3·16	1	7·5 9·2	·030	W.B.
B.D. +22°·1280	6 14	67 51	51·4	1·69	3	8·7 8·7	·090	W.B.
Ho. 232 ...	6 16	75 16	353·4	2·75	1	9·5 11·0	·225	H.F.
Ho. 25 ...	6 16	64 43	244·5	0·76	3	8·8 9·0	·201	W.B.
			248·9	0·90	1	...	·208	H.F.
Σ 899 ...	6 17	72 22	22·6	2·27	1	7·0 8·0	·047	W.B.
Ho. 233 ...	6 17	73 26	37·9	2·08	3	8·2 11·0	·180	W.B.
B.D. +24°·1270	6 21	65 24	208·1	2·79	2	9·0 9·1	·056	W.B.
β 1021 ...	6 25	61 32	93·6	0·75	1	8·0 9·0	·208	H.F.
OΣ 149 ...	6 30	62 38	267·8	0·80	2	6·5 9·0	·188	H.F.
B.D. +23°·1480	6 39	66 27	79·3	1·75	2	8·5 9·0	·056	W.B.
Ho. 328 ...	6 41	71 41	189·4	0·39	3	8·5 8·5	·180	W.B.
β 899 ...	6 55	71 9	265·0	0·78	1	8·7 9·3	·208	H.F.
B.D. +24°·1508	6 57	65 24	21·2	1·63	2	9·0 9·2	·056	W.B.
OΣ 165 ...	7 3	73 55	36·0	4·30	1	5·0 10·7	·167	L.
Ho. 518 ...	7 4	59 30	147·5	2·77	1	8·0 10·0	·044	W.B.
			151·6	2·82	1	...	·225	H.F.
Σ 1037 ...	7 7	62 36	295·3	0·70	2	7·1 7·1	·211	W.B.
W.B. (2) VII. 118	7 7	74 40	156·1	2·02	3	8·2 8·7	·138	W.B.
			159·0	1·87	1	...	·156	L.
OΣ 170 ...	7 12	80 32	107·7	1·41	3	7·5 7·5	·133	W.B.
			107·4	1·62	2	...	·162	L.
Σ 1066 ...	7 14	67 50	207·3	6·72	1	3·2 8·2	·183	W.B.
Ho. 243 ...	7 16	60 33	166·9	2·20	2	9·3 9·5	·230	W.B.
			166·5	2·36	1	...	·241	L.
β 1024 ...	7 16	60 31	89·4	1·46	1	9·0 11·0	·244	W.B.
B.D. +22°·1678	7 20	67 43	176·1	2·14	2	8·7 10·3	·162	W.B.
Procyon ...	7 34	84 31	5·3	4·46	1	0·5 14	·167	L.
Σ 1126 ...	7 35	84 32	143·3	1·13	1	7·2 7·5	·205	W.B.
Ho. 247 ...	7 40	68 42	108·2	0·42	4	7·5 8·0	·163	W.B.
			109·8	0·48	1	...	·208	H.F.
Ho. 36 ...	7 41	64 18	298·1	0·60	3	8·5 8·5	·145	W.B.
Σ 1196 AB	8 6	72 3	349·1	1·14	3	5·0 5·7	·234	W.B.
AC	...	...	109·6	5·51	3	5·0 6·5	·234	W.B.

Star's Name.	R.A. 1900. h m	N.P.D. 1900. ° ′	Position Angle. °	Distance. ″	No. of Nights.	Mags.	Epoch 1905.	Obs.
Σ 1196 BC	...	...	121·1	6·13	3	5·7 6·5	·234	W.B.
$\frac{AB}{2}$ C	...	...	114·8	5·45	2	5·0 6·5	·190	W.B.
B.D. + 23°·1978	8 31	66 24	184·1	1·54	3	9·2 10·2	·150	W.B.
Ho. 354 ...	8 36	63 35	181·4	0·57	1	8·2 8·8	·159	W.B.
			182·0	0·87	2	...	·255	H.F.
Ho. 251 ...	8 40	64 19	154·0	3·57	1	8·5 12·2	·277	Bk.
			153·0	4·00	1	...	·277	W.B.
Σ 1273 $\frac{AB}{2}$ C	8 41	83 13	231·6	3·33	1	3·8 7·7	·285	H.F.
B.D. + 23°·2004	8 45	66 30	258·6	2·24	1	9·0 9·1	·225	H.F.
			257·5	2·20	2	...	·269	W.B.
			257·0	2·00	2	...	·269	Bk.
Ho. 43 ...	9 13	68 47	302·7	0·47	1	8·0 8·5	·277	W.B.
			296·5	0·43	1	...	·277	Bk.
OΣ 201 ...	9 18	61 39	223·6	1·66	2	7·5 9·0	·174	W.B.
Σ 1348 ...	9 19	83 13	324·8	1·78	1	7·5 7·6	·219	L.
			319·2	1·98	2	...	·255	W.B.
Ho. 368 ...	9 32	64 12	105·0	1·01	3	8·5 8·9	·229	W.B.
			112·9	1·13	2	...	·255	H.F.
			110·5	1·09	1	...	·285	Bk.
Σ 1389 ...	9 47	62 32	307·3	2·30	2	8·0 9·0	·186	W.B.
W.B.(2)X. 128–9	10 9	71 38	6·5	1·25	3	8·0 8·5	·235	W.B.
			10·2	1·77	1	...	·277	Bk.
OΣ 215 ...	10 11	71 46	206·1	0·90	4	7·0 7·2	·238	W.B.
			206·3	1·22	1	...	·225	H.F.
Σ 1424 ...	10 14	69 39	113·3	3·60	2	2·0 3·5	·225	W.B.
			116·5	3·70	1	...	·260	Bk.
Σ 1429 ...	10 20	64 53	250·2	1·02	2	8·3 8·3	·214	W.B.
OΣ 227 ...	10 36	78 44	341·0	0·64	1	7·5 8·5	·353	L.
Σ 1523 ...	11 13	57 54	137·2	2·62	1	4·0 5·0	·189	W.B.
Σ 1527 ...	11 14	75 11	16·1	3·38	1	6·9 8·1	·260	W.B.
			16·5	3·45	1	...	·260	Bk.
Σ 1536 ...	11 19	78 55	55·0	2·36	2	3·9 7·1	·284	L.
			50·3	2·18	2	...	·255	W.B.
Lalande 21846	11 24	58 59	4·7	0·95	2	7·0 11·5	·286	L.
OΣ 235 ...	11 27	28 22	178·7	0·35	1	6 7	·277	W.B.

Star's Name.		R.A. 1900. h m	N.P.D. 1900. ° ′	Position Angle. °	Distance. ″	No. of Nights.	Mags.	Epoch 1905.	Obs.
OΣ 235	...	11 27	28 22	182·2	0·35	1	6 7	·277	Bk.
β 603	...	11 44	75 10	310·8	...	1	6·4 10·2	·219	L.
				319·5	1·01	1	...	·353	L.
Ho. 255	...	12 2	68 57	133·2	2·15	1	8·2 12·3	·353	L.
Ho. 536	...	12 16	54 26	97·4	3·84	1	8·5 9·7	·241	L.
				95·6	3·41	1	...	·320	W.B.
Σ 1639	...	12 20	63 52	353·3	0·36	1	6·7 7·9	·372	W.B.
Σ 1643	...	12 22	62 25	37·7	2·22	1	8·7 9·2	·260	W.B.
				38·4	2·14	1	...	·260	Bk.
Σ 1687	...	12 48	68 13	84·1	1·23	1	5·2 8·0	·348	L.
Σ 1728	...	13 5	71 57	193·7	0·60	1	6·0 6·0	·348	L.
				193·2	0·49	1	...	·372	W.B.
Ho 260	...	13 19	60 15	312·9	0·76	1	8·3 8·5	·342	W.B.
β 113	...	13 24	78 0	203·7	1·33	1	8·2 11·0	·285	H.F.
				200·6	1·75	1	...	·285	Bk.
β 801	...	13 41	78 40	325·2	2·88	1	8·2 10·2	·405	L.
				326·6	2·83	1	...	·285	H.F.
				327·7	2·59	1	...	·285	Bk.
Σ 1785	...	13 45	62 31	297·7	1·55	3	7·2 7·5	·313	W.B.
				304·3	1·42	1	...	·285	H.F.
				300·8	1·51	2	...	·281	Bk.
Σ 1863	...	14 35	38 0	86·2	0·65	2	7·1 7·4	·299	W.B.
Σ 1865	...	14 36	75 51	143·8	0·37	1	3·5 3·9	·413	W.B.
Hu. 575	...	14 38	70 5	152·5	0·69	1	9·0 9·5	·405	L.
Σ 1871	...	14 38	39 11	294·6	1·90	2	7·0 7·0	·299	W.B.
Hu. 576	...	14 41	69 25	190·5	5·00	1	8·2 13·0	·405	L.
Σ 1888	...	14 47	70 29	174·1	2·41	2	4·7 6·6	·463	W.B.
β 31...	...	14 48	70 51	198·6	1·51	1	8·4 9·7	·512	W.B.
OΣ 288	...	14 49	73 53	187·7	1·72	1	6·4 7·2	413	W.B.
Σ 1909	...	15 1	41 57	241·9	4·32	1	5·2 6·1	·350	W.B.
				245·4	4·36	1	...	·353	L.
Σ 3090	...	15 4	90 35	99·9	1·56	1	8·8 8·9	·449	L.
Ho. 60	...	15 10	54 44	42·7	0·45	1	8·0 8·0	·353	L.
Σ 1932	...	15 14	62 48	152·9	0·48	1	5·6 6·1	·350	W.B.
Σ 1938	...	15 21	52 18	65·2	1·06	3	6·7 7·3	·356	L.
Hu. 649	...	15 21	40 7	50·2	4·44	2	8·2 13·0	·371	L.
Σ 1941	...	15 22	63 2	223·2	1·73	1	8·7 8·7	·367	L.
Ait. 82	...	15 23	65 44	311·1	0·98	1	8·5 9·3	·512	W.B.

Star's Name.		R.A. 1900. h m	N.P.D. 1900. ° ′	Position Angle. °	Distance. ″	No. of Nights.	Mags.	Epoch 1905.	Obs.
OΣ 296	...	15 23	45 39	304·6	1·48	1	...	·350	W.B.
				306·9	1·72	1	7·0 8·6	·367	L.
Σ 1950	...	15 26	64 9	91·0	4·07	1	6·7 8·2	·367	L.
Hu. 651	...	15 26	39 13	343·0	1·03	2	8·2 12·8	·371	L.
Σ 1956	...	15 30	47 51	40·0	1·97	2	8·0 9·4	·310	W.B.
Σ 1959	...	15 31	54 57	242·1	2·27	1	8·7 10·2	·277	W.B.
OΣ 298	...	15 33	49 52	187·6	1·17	1	7·0 7·3	·350	W.B
Hu. 652	...	15 33	40 51	175·7	0·79	1	8·5 8·8	·367	L.
Σ 1967	...	15 39	63 23	118·0	0·72	2	4·0 7·0	·360	L.
Σ 1969	...	15 39	29 40	49·5	0·52	1	8·0 8·7	·386	W.B.
				49·8	0·60	1	...	·386	H.F.
Hu. 657	...	15 43	39 1	310·5	0·57	1	8·5 8·5	·367	L.
β 621	...	15 47	45 8	54·7	0·40	1	7·5 8·0	·367	L.
Hu. 658	...	15 51	38 16	341·9	2·63	1	8·4 13·0	·367	L.
Σ 3101	...	15 54	92 47	68·7	2·37	1	8·2 8·5	·449	L.
Σ 1991	...	15 54	48 3	198·0	3·56	2	8·2 9·5	·309	W.B.
Σ 2000	...	15 56	75 45	225·9	2·46	1	8·2 9·0	·389	W.B.
OΣ 303	...	15 56	76 27	142·5	0·80	1	7·4 7·9	·512	W.B.
Σ 2004	...	15 59	60 52	276·1	1·45	1	8·7 9·7	·350	W.B.
Σ 2005	...	16 0	96 1	143·6	1·43	1	6·5 8·8	·449	L.
Σ 2011	...	16 4	60 44	70·3	2·63	1	7·2 9·8	·397	W.B.
Σ 2025	...	16 8	42 11	165·2	2·69	1	7·6 10·9	·367	L.
Σ 2032	...	16 11	55 54	216·3	4·80	1	5·0 6·1	·397	W.B.
Σ 2037	...	16 14	72 22	242·9	1·45	1	9·0 9·0	·389	W.B.
Σ 2055	...	16 26	87 48	60·5	1·18	2	4·0 6·1	·466	L.
				59·6	1·52	1	...	·468	W.B.
Σ 2061	...	16 29	58 55	22·8	2·38	1	7·1 9·9	·389	W.B.
Σ 2080	...	16 35	51 28	25·3	3·17	1	8·0 11·8	·389	W.B.
Σ 2084	...	16 38	58 13	187·1	1·40	2	3·0 6·5	·527	W.B.
Σ 2091	...	16 39	48 37	304·8	0·98	2	7·5 8·0	·385	W.B.
De. 15	...	16 41	46 20	303·4	0·46	1	8·2 8·6	·397	W.B.
Σ 2106	...	16 46	80 25	296·2	0·35	1	6·7 8·4	·468	W.B.
				305·2	0·32	1	...	·482	L.
Σ 2107	...	16 48	61 10	354·0	0·34	2	6·5 8·0	·477	W.B.
				357·0	0·35	1	...	·482	L.
Σ 3106	...	16 50	85 1	252·3	2·28	1	8·6 8·6	·545	W.B.
Σ 2112	...	16 54	58 3	258·8	1·98	2	8·5 9·5	·393	W.B.
Σ 2114	...	16 57	81 24	160·8	0·97	1	6·2 7·4	·389	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.		Epoch 1905.	Obs.
	h m	° ′	°	″					
Σ 2156 ...	17 19	90 45	34·8	3·38	2	8·3	9·0	·537	W.B.
Ho. 415 ...	17 19	64 9	331·8	1·17	2	8·0	8·7	·527	W.B.
Σ 2162 ...	17 20	53 25	279·2	1·37	1	8·7	9·2	·446	L.
B.D. +36°·2862	17 19	53 7	255·7	1·54	1	8·7	10·0	·446	L.
Σ 2168 ...	17 23	54 10	200·0	2·56	1	7·5	8·2	·397	W.B.
			197·4	2·46	1	...		·449	L.
Σ 2170 ...	17 24	79 26	270·5	3·88	1	8·5	9·0	·449	L.
Σ 2187 ...	17 31	85 48	177·0	2·99	1	8·3	9·3	·454	H.F.
Σ 2186 ...	17 31	88 56	79·6	2·77	1	7·5	7·5	·454	H.F
Σ 2200 ...	17 39	84 6	167·7	1·42	1	8·0	8·8	·454	H.F.
Σ 2205 ...	17 40	72 14	308·7	1·98	1	8·3	8·7	·512	W.B.
Σ 2206 ...	17 40	71 58	246·5	1·30	2	8·1	9·7	·477	W.B.
Σ 2215 ...	17 41	72 15	294·3	0·71	1	5·9	7·9	·512	W.B.
Σ 2212 ...	17 41	84 16	337·7	3·13	1	8·5	8·8	·482	L.
			340·3	3·13	1	...		·528	W.B.
Σ 2222 ...	17 43	75 7	59·7	2·35	2	7·5	9·2	·471	W.B.
Σ 2233 ...	17 47	87 4	73·2	2·72	1	7·5	10·3	·490	L.
Σ 2239 ...	17 48	61 43	318·6	2·55	2	8·5	9·0	·471	W.B.
Aitken 234	17 49	64 23	19·5	0·48	1	8·8	9·1	·481	L.
Σ 2240 ...	17 49	84 44	199·4	2·97	2	9·0	9·7	·479	W.B.
Aitken 235	17 49	64 59	69·7	0·46	1	7·9	8·1	·481	L.
Σ 2244 ...	17 52	89 55	278·9	1·05	1	6·9	7·1	·490	L.
Σ 2245 ...	17 52	71 39	113·3	2·70	2	7·0	7·0	·471	W.B.
Σ 2250 ...	17 54	96 51	166·6	7·45	1	8·0	9·0	·515	H.F.
Σ 2252 ...	17 54	87 57	23·6	4·01	2	8·0	8·3	·479	W.B.
Σ 2254 ...	17 54	77 33	265·1	3·43	2	8·3	8·7	·479	W.B.
Ho. 565 ...	17 59	63 56	67·1	0·55	1	8·3	8·3	·481	L.
Σ 2272 ...	18 1	87 27	178·2	2·10	12	4·5	6·0	·562	W.B.
Σ 2281 ...	18 5	86 1	Star round		1	5·7	7·2	·616	L.
			16·2	0·18	2	...		·700	W.B.
Σ 2292 ...	18 8	62 23	271·2	1·05	1	8·0	8·1	·624	L.
Σ 2294 ...	18 9	89 51	279·6	0·38	1	7·4	7·7	·616	L.
Σ 2303 ...	18 15	98 2	223·7	2·36	1	6·7	9·2	·622	W.B.
Σ 2314 ...	18 19	66 36	329·4	2·64	2	8·4	9·6	·480	W.B.
Ho. 83 ...	18 20	62 29	92·7	0·69	2	8·2	8·4	·616	L.
			87·9	0·70	1	...		·726	W.B.
Ho. 84 ...	18 20	62 37	317·7	3·81	1	9·0	11	·481	L.
			315·6	4·33	1	...		·726	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1905.	Obs.
	h m	° ′	°	″				
Σ 2315 ...	18 21	62 40	197·3	0·27	1	7·0 8·0	·481	L.
Ho. 85 ...	18 22	61 57	194·4	5·05	2	8·0 12	·549	L.
Σ 2319 ...	18 23	70 46	189·2	5·33	2	7·2 7·7	·480	W.B.
Σ 2328 ...	18 26	60 9	72·5	3·47	2	8·0 8·3	·664	W.B.
			71·4	3·81	1	...	·481	L.
Σ 2341 ...	18 30	78 38	181·3	1·74	1	8·5 9·7	·481	L.
Σ 2347 ...	18 33	90 28	256·5	3·04	1	7·5 9·4	·622	W.B.
Ho. 437 AB	18 37	58 27	302·1	0·43	1	8·3 8·5	·674	L.
CD	...	...	336·7	3·21	1	...	·674	L.
			288·1	22·29	1	...	·674	L.
Σ 2367 AB	18 37	59 48	74·4	0·31	1	7·0 7·5	·674	L
AC	...	...	193·2	19·48	1	...	·674	L.
Σ 2397 ...	18 43	58 42	265·2	3·90	2	7·2 9·5	·664	W.B.
Σ 2402 ...	18 45	79 26	203·4	0·97	1	8·0 8·4	·701	L.
β 647 ...	18 52	76 32	9·1	0·96	2	9·0 9·2	·711	W.B
B.D. +15°·3627	18 52	74 21	33·8	1·15	1	8·5 9·5	·682	L.
Hu. 676 ...	18 53	74 18	10·8	3·15	1	7·2 10·0	·674	L.
B.D. + 14°·3718, AB	18 53	74 12	103·2	1·62	1	8·9 10·0	·682	L.
Σ 2426 BC	18 55	77 16	168·2	3·08	2	8·2 11	·692	L.
Hu. 677 ...	18 56	77 6	219·7	1·06	1	8·8 9·5	·701	L.
Ho. 93 ...	18 58	75 43	323·0	1·19	2	7·5 12·0	·711	W.B.
			317·5	1·14	1	...	·682	L.
Σ 2481 ...	19 8	51 24	220·9	4·03	1	8·0 8·0	·695	W.B.
Σ 2502 ...	19 16	50 56	206·2	1·70	1	8·2 10·2	·695	W.B.
Ho. 576 ...	19 16	83 22	182·1	4·19	1	7·0 10·7	·616	L.
Σ 2505 ...	19 16	54 38	315·4	10·79	1	8·0 8·7	·695	W.B.
Σ 2525 ...	19 23	62 52	312·8	0·66	3	7·5 7·7	·761	W.B.
Σ 2599 ...	19 49	67 17	53·6	3·91	1	7·8 9·5	·539	L.
			50·7	4·14	1	...	·545	W.B.
Σ 2600 ...	19 51	67 47	54·9	3·67	1	8·3 9·7	·539	L.
			57·3	3·25	1	...	·545	W.B.
A.C. 16 ...	19 54	63 1	56·4	0·39	1	7·8 8·2	·800	W.B.
B.D. +21°·3994	19 54	68 8	277·7	1·53	1	9·0 10·4	·758	W.B.
Ho. 583 ...	19 55	68 10	255·8	1·53	1	9·0 10·7	·726	W.B
OΣ 395 ...	19 58	65 20	104·1	0·68	1	5·8 6·2	·800	W.B
Σ 2616 ...	19 58	75 42	261·8	3·85	1	6·8 9·7	·539	L.

Star's Name.		R.A. 1900. h m	N.P.D. 1900. ° ′	Position Angle. °	Distance. ″	No. of Nights.	Mags.	Epoch 1905.	Obs.
Σ 2616	..	19 58	75 42	264·2	3·52	1	6·8 9·7	·545	W.B.
Σ 2620	...	19 59	78 30	285·3	2·05	2	8·2 9·3	·548	W.B.
Σ 2626	...	20 0	59 45	122·9	1·28	2	8·0 8·2	·635	W.B.
Σ 2651	...	20 9	74 9	101·8	1·63	2	8·0 8·0	·548	W.B.
Σ 2662	...	20 14	79 20	43·0	1·92	3	8·2 11·0	·650	W.B
Σ 2666	...	20 15	49 35	241·6	2·48	1	6·5 8·7	·685	H.F.
Σ 2665	...	20 15	75 57	18·8	3·65	1	6·5 9·2	·545	W.B.
Σ 2672	...	20 17	66 34	293·7	1·01	3	8·7 8·8	·653	W.B.
Σ 2673	...	20 18	77 0	329·9	2·39	2	8·0 9·5	·623	W.B.
Σ 2676	...	20 19	63 11	169·2	2·35	2	7·8 10·0	·623	W.B.
β 670	...	20 28	76 24	38·8	0·57	1	8·5 8·9	·726	W.B.
Σ 2696	...	20 29	84 54	300·6	0·74	3	8·0 8·4	·717	H.F
Σ 2703	...	20 32	75 37	219·1	2·37	2	7·6 7·6	·613	W.B
Σ 2701	...	20 32	78 18	204·7	3·42	1	7·8 8·2	·813	H.F.
β 151	...	20 33	75 45	51·3	0·25	2	4·7 6·1	·763	W.B.
Σ 2711	...	20 35	59 51	223·8	2·14	1	8·0 9·0	·690	H.F.
				223·3	2·35	2	...	·723	W.B.
Σ 2716	...	20 37	58 3	46·3	2·22	1	6·0 8·2	·685	H.F.
Σ 2720	...	20 39	73 25	180·3	3·83	2	8·5 8·7	·691	W.B.
Σ 2721	...	20 39	70 29	29·8	2·51	2	8·0 10·0	·698	W B.
Σ 2724	...	20 40	66 26	146·7	2·50	2	8·2 8·3	·691	W.B.
Σ 2723	...	20 40	78 3	103·1	1·35	2	7·3 8·0	·613	W.B.
Σ 2726	...	20 42	59 39	362·9	5·31	2	4·0 9·2	·696	H.F.
Σ 2730	...	20 46	84 0	337·2	3·50	2	7·8 7·9	·695	H.F.
Σ 2735	...	20 51	85 51	285·3	2·07	2	6·2 7·7	·718	W.B.
				285·4	2·05	1	...	·685	H.F.
Σ 3113	...	20 55	29 2	91·6	1·21	1	8·7 8·7	·033	H.F.
OΣ 527	...	21 3	85 15	271·1	0·35	1	6·5 8·0	·800	W.B.
Σ 2765	...	21 6	80 51	264·4	3·12	2	7·8 8·0	·701	W.B.
Ho. 152	...	21 8	62 4	322·0	0·42	1	8·4 8·5	·800	W.B.
OΣ 535	...	21 10	80 24	8·2	0·24	4	4·5 5·0	·766	L.
				7·3	0·22	8	...	·800	W.B.
				2·2	0·30	3	...	·797	H.F.
Σ 2802	...	21 38	56 38	188·3	3·78	3	8·0 8·0	·828	W.B.
Ho. 165	...	21 38	71 29	73·8	0·36	2	8·0 8·2	·760	W.B.
				79·8	0·39	1	...	·846	L.
Ho. 166	...	21 40	62 38	82·2	0·33	1	7·5 7·5	·717	L.
				82·8	0·33	3	...	·735	W.B.

Star's Name.	R.A. 1900.	N.P.D. 1900.	Position Angle.	Distance.	No. of Nights.	Mags.	Epoch 1905.	Obs.
	h m	° ′	°	″				
β 89 ...	21 40	64 49	113·3	0·23	3	3·9 4·4	·797	L.
			113·3	0·26	9	...	·809	W.B.
			112·0	0·37	3	...	·800	H.F.
Σ 2824 ...	21 40	64 49	297·9	12·62	2	4·3 10·0	·739	W.B.
			297·3	12·49	1	...	·717	L.
Hu. 693 ...	21 40	39 54	226·0	1·07	1	8·7 9·2	·895	W.B.
Σ 2825 ...	21 42	89 36	117·3	0·98	1	8·0 8·2	·895	W.B.
Ho. 608 ...	21 42	63 10	123·2	0·49	2	8·2 9·7	·782	L.
Ho. 467 ...	21 46	68 13	187·2	1·27	1	8·0 10·2	·895	W.B.
Ho. 171 ...	21 48	62 41	171·8	0·81	4	8·0 8·2	·791	W.B.
Ho. 609 AB	21 51	60 45	357·5	3·16	1	9·5 9·8	·909	L.
Σ 2847 ...	21 53	93 58	301·4	1·12	1	7·6 8·0	·895	W.B.
Ho. 610 ...	21 57	63 38	224·4	0·69	1	9·0 9·2	·717	L.
Σ 2856 ...	22 1	85 37	199·4	1·27	1	8·2 8·8	·895	W.B.
Σ 2862 ...	22 2	89 55	101·7	2·58	1	7·8 7·9	·895	W.B.
Ho. 179 ...	22 8	60 20	266·1	0·45	4	8·0 8·5	·823	W.B.
Σ 2900 ...	22 19	63 39	177·8	1·38	2	...	·775	W.B.
			181·5	1·51	2	6·0 9·2	·878	L.
Espin. 147 ...	22 21	35 29	18·6	2·42	1	8·3 10·2	·895	W.B.
Σ 2905 ...	22 22	75 42	283·1	3·24	1	8·0 8·0	·909	L.
Σ 2906 ...	22 22	53 4	3·1	4·03	1	7·0 10·6	·706	H.F.
Ho. 475 ...	22 28	64 4	318·8	0·79	3	8·0 8·2	·847	W.B.
Ho. 480 ...	22 34	61 0	229·2	0·69	1	8·0 9·1	·758	W.B.
Σ 2929 ...	22 34	79 59	175·3	2·01	1	9·0 9·5	·830	W.B.
Ho. 296 ...	22 36	75 59	72·3	0·35	2	5·5 5·5	·848	W.B.
Σ 2934 ...	22 37	69 5	138·8	0·86	2	8·2 9·2	·843	W.B.
Σ 2942 ...	22 40	51 4	281·3	2·81	1	6·5 8·8	·794	H.F.
			282·6	2·67	1	...	·936	W.B.
Σ 3000 ...	23 14	65 20	50·2	3·10	1	8·7 8·8	·025	W.B.
Ho. 489 ...	23 21	62 48	238·1	0·46	3	7·5 7·5	·871	W.B.
β 720 ...	23 29	59 14	178·3	0·29	1	5·9 6·0	·887	W.B.
Σ 3026 ...	23 31	61 39	279·8	3·21	1	8·8 9·3	·025	W.B.
Ho. 201 ...	23 32	55 55	341·9	3·71	1	8·0 9·3	·936	W.B.
Ho. 203 ...	23 34	55 0	132·4	3·54	1	9·0 10·0	·936	W.B.
β 858 ...	23 36	58 0	261·1	0·55	1	7·7 8·2	·887	W.B.
β 994 ...	23 39	65 27	299·1	1·41	1	7·9 11·0	·909	L.
A.G.C. 14 ...	23 39	61 12	200·7	1·24	1	5·0 9·5	·887	W.B.
Ho. 206 ...	23 54	56 17	187·8	2·06	1	8 10	·936	W.B.

The New Reduction of the Meridian Observations of Groombridge.
By Lewis Boss.

More than a year in advance of publication the Astronomer Royal at Greenwich kindly transmitted to me a manuscript catalogue of certain desired star positions newly deduced from the observations of Groombridge, 1810, by Frank W. Dyson, F.R.S., and William G. Thackeray, F.R.A.S., and later a set of revised proofs of the ledger of observations. This afforded an opportunity for comparison with my standard catalogue as well as for the extension of the same. After the work on the three higher of our five classes of stars had been substantially completed, it was found that there were available for comparison 570 well determined stars in common with positions taken from the revised catalogue of Groombridge. Accordingly a careful comparison of these stars was executed, in order to determine the relation of Groombridge's positions (revised) to those of the enlarged Standard Catalogue. The results of this comparison are outlined in the present communication.

The system of standards employed is essentially that of the *Catalogue of 627 Principal Standard Stars* (*Astron. Journ.*, Nos. 531–2), slightly modified in minor details since that publication. The results here presented are derived from the later of two successive approximations, each element of systematic correction having been essentially freed from the effect of other elements previous to the definitive derivation.

It became evident on examining the comparisons in R.A. that the element of difference, Stand.–Groomb., that has for its argument R.A. ($\Delta\alpha_a$ and $\Delta'\alpha_a \tan\delta$), is, on the whole, the more important as well as complicated. Eliminating the greater part of the difference having the argument declination, and arranging in zones, we have the differences, S.–G., in Table I. In order to fit these residual differences for the treatment finally adopted they are converted into $\Delta\alpha\cot\delta$, which in the close polar zone does not differ very greatly from $\Delta\alpha\cos\delta$.

It is known that the transit observations of Groombridge do not usually afford the means for satisfactory determination of the polar deviation of the line of collimation. The authors call particular attention to this (Int., p. 10). Moreover the adopted values of collimation are liable to much uncertainty. We may, therefore, anticipate that there will be errors in the deduced right ascensions of the form $n\tan\delta$, or the form $n\left(1-\tan\frac{90^\circ-\delta}{2}\right)$. The origin of the latter form of correction is to be attributed to a defective determination of the collimation, as Professor Turner has pointed out (*Monthly Notices*, vol. xlvi.), and it may exist when $n\tan\delta$ is otherwise well determined.

TABLE I.

Stand.–Groomb., $\Delta\alpha_\alpha \cot\delta$.

Zone I. 38° to 55°, decl.

R.A.	No of Stars.	$\Delta\alpha \cot\delta$.	Calc.
h		s	s
23·8	26	−·009	+·007
2·1	27	+·004	+·008
4·1	16	+·027	+·007
6·0	16	−·003	+·004
8·1	11	−·021	·000
9·8	19	+·022	−·004
12·0	18	+·002	−·007
14·0	17	−·015	−·008
15·9	20	−·018	−·007
17·9	18	−·006	−·004
19·9	28	+·028	·000
21·9	24	−·002	+·004

Zone II. 56° to 66°, decl.

R.A.	No of Stars.	$\Delta\alpha \cot\delta$.	Calc.
h		s	s
23·8	15	−·006	−·007
1·6	7	+·010	−·013
4·1	7	−·029	−·018
6·1	9	−·009	−·016
7·9	11	−·029	−·010
10·3	12	+·002	·000
12·5	7	+·001	+·010
13·7	9	−·004	+·013
16·3	9	+·012	+·018
18·7	9	−·016	+·014
20·1	16	+·003	+·010
22·0	15	+·002	+·001

Zone III. 67° to 77°, decl.

R.A.	No. of Stars.	$\Delta\alpha \cot\delta$.	Calc.
h		s	s
0·8	9	−·026	−·021
1·8	11	−·035	−·026
3·8	2	−·057	−·031
6·0	6	−·035	−·026
8·2	7	+·033	−·014
9·9	7	−·063	−·001
12·1	7	+·009	+·016
14·3	6	+·058	+·028
16·0	6	+·002	+·031
18·4	12	+·020	+·024
19·9	11	+·030	+·016
21·8	12	−·004	+·002

Zone IV. 78° to 90°, decl.

R.A.	No of Stars.	$\Delta\alpha \cot\delta$.	Calc.
h		s	s
0·4	9	+·006	−·027
2·6	3	+·053	−·040
3·9	8	−·027	−·043
6·2	6	−·048	−·035
7·5	5	−·081	−·024
10·1	6	−·008	+·003
12·2	8	+·088	+·025
13·7	4	+·082	+·036
15·8	7	+·073	+·043
18·2	5	·000	+·035
20·5	5	+·010	+·014
22·2	9	−·029	− 004

TABLE II.

Special Tabulation of $\Delta' a_n \cot \delta$, Decl. 56° to 90°.

R.A.	Zone II.	Zone III.	Zone IV.	Weighted Mean.	Calc.
h	s	s	s	s	s
0	−·024	−·040	+·003	−·023	−·027
2	−·018	−·052	+·049	−·034	−·045
4	−·061	−·076	−·031	−·054	−·050
6	−·034	−·050	−·051	−·043	− 042
8	−·042	+·027	−·083	−·029	−·023
10	+·009	−·061	−·007	−·015	+·003
12	+·022	+·021	+·091	+·045	+·027
14	+·025	+·076	+·086	+·052	+·045
16	+·044	+·021	+·077	+ 046	+·050
18	+·006	+·034	+·004	+·020	+·042
20	+·015	+·038	+·011	+·022	+·023
22	−·002	−·005	−·030	−·008	−·003

Inspection of Table I. led to the conclusion that there exist sensible systematic errors in the determination of n for the transits of Groombridge, and that these errors vary with the season, or rather with the right-ascension. Accordingly it was assumed that the forty-eight mean values of $\Delta a \cot \delta$ could be systematically represented by the formula

$$a \cot \delta \sin \alpha + b \cot \delta \cos \alpha + a' \sin \alpha + b' \cos \alpha,$$

in which a' and b' are coefficients of the periodic correction supposed to originate in defective determination of $n \tan \delta$, and a and b similar coefficients which would have been attributable to right-ascensions of Groombridge observed near the equator. The whole material duly weighted and treated rigorously by the method of least squares results in the following values of the respective coefficients of correction :—

$$a = +\overset{s}{\cdot}047 \pm \overset{s}{\cdot}010 \qquad a' = -\overset{s}{\cdot}042 \pm \overset{s}{\cdot}007$$
$$b = +\cdot 035 \pm \cdot 010 \qquad b' = -\cdot 027 \pm \cdot 007$$

The probable errors are large, partly because the precision of the right-ascensions is unavoidably small, and partly because of a considerable degree of indetermination between a and b compared with a' and b'. The quantities in Table I. under "Calc." are computed from the formula :—

$$+^{s}\cdot 047 \cot \delta \sin \alpha + ^{s}\cdot 035 \cot \delta \cos \alpha - ^{s}\cdot 042 \sin \alpha - ^{s}\cdot 027 \cos \alpha.$$

This is equivalent to

$$+^{s}\!\cdot\!047 \sin \alpha +^{s}\!\cdot\!035 \cos \alpha -^{s}\!\cdot\!042 \sin \alpha \tan \delta -^{s}\!\cdot\!027 \cos \alpha \tan \delta$$

applied directly to the right-ascensions of the Catalogue.

The probable error of a right-ascension of Groombridge based on five observations is about $\pm^{s}\!\cdot\!04$, so that the representation of the observed values of $\Delta\alpha \cot \delta$ by the calculated values is, perhaps, as good as could have been expected. The validity of the adopted formula may be examined in another way. At 45° of N.P.D. the entire correction becomes $+^{s}\!\cdot\!005 \sin \alpha + ^{s}\!\cdot\!008 \cos \alpha$, and this seems fairly consistent with the procedure adopted by the authors of employing as additional clock-stars "all stars between 35° and 52° N.P.D. for which reliable places could be found" (Int., p. x); since it may be assumed that the standard places adopted (largely those of Newcomb's fundamental catalogue) are measurably free from error of the form $\Delta\alpha_{\alpha}$. A further test of the applicability of the formula can be found by subtracting the effect of a and b in zones II., III., and IV. of Table I., leaving only the observed effect of periodic terms in a' and b'. The result of this process is shown in Table II. The column under "Mean" exhibits the observed coefficients of correction in the term $\Delta'\alpha_{\alpha} \tan \delta$ collected into weighted means from the three zones—*i.e.* N.P.D. 34° to the pole. These should be consistent with the adopted correction,

$$-^{s}\!\cdot\!042 \sin \alpha -^{s}\!\cdot\!027 \cos \alpha$$

computed for two-hour intervals under the caption, "Calc." The real existence of a general term of this nature appears to be clearly indicated. This implies that if, with the adopted values of clock-corrections and $n \tan \delta$, the right-ascensions of equatorial stars observed by Groombridge should be computed, they would require a correction of approximately $+^{s}\!\cdot\!047 \sin \alpha + ^{s}\!\cdot\!035 \cos \alpha$. Some support of this probability is indicated by means of the table, pp. xxxv–xxxvii, in the introduction of the Catalogue, though no solid conclusion can be drawn from numbers subject to the large and irregular discrepancies which characterise these.

The most that we can hope for in a case of this kind is to remove a general systematic error, trusting that the still outstanding errors may be treated as if they were of the same general nature as casual errors of observation. The value of systematic corrections in general seems to pertain less to their influence upon computations concerning an individual star than to those which relate to large numbers of stars in a limited region of sky. Thus a systematic error of $^{s}\!\cdot\!02 \sec \delta$ in the right-ascension of a close circumpolar star employed in deducing $n \tan \delta$ for a transit instrument could not be matter of much concern; but a systematic error of this amount applicable to all the polar stars of several contiguous hours of right-ascension, employed in

computation of $n \tan \delta$ for many nights, would be of serious consequence in accurate work.

The treatment of the right-ascensions for systematic errors depending on declination as the argument presents no points of special interest in this instance. The results are exhibited in Table III. The residuals of this table are, for the most part,

Table III.

Corrections Dependent on Decl., $\Delta\alpha_\delta$.

Mean δ.	No. of Stars.	Observed $\Delta\alpha_\delta \cos\delta$.	Observed $\Delta\alpha_\delta$.	Mean δ.	No. of Stars.	Observed $\Delta\alpha_\delta \cos\delta$.	Observed $\Delta\alpha_\delta$.
°		s	s	°		s	s
86	34	+·016	+·23	55	64	+·001	+·002
81	42	+·006	+·04	50	72	−·006	−·009
75	36	+·005	+·02	45	71	−·030	−·043
70	48	+·009	+·025	40	87	−·007	−·009
65	52	−·006	−·015				
60	58	−·016	−·032				

really minute. Those at 60° and 45° may indicate local effects due to slight inequalities in the form of the pivots, and some weight has been attached to this idea in drawing the curve of correction, of which the following exhibits the general result :—

δ.		δ.	
°	s	°	s
90	+·010 sec δ	65	−·012
85	+·010 sec δ	60	−·018
80	+·010 sec δ	55	−·010
80	+·058	50	−·018
75	+·035	45	−·028
70	+·009	40	−·018

The exigencies of space will not permit a full exposition of the method of dealing with the personal equation for magnitude affecting the right-ascensions of Groombridge. I may venture to say, however, that it has been possible to construct a catalogue of standard right-ascensions that appears, both as to positions and motions, to be practically free from the effect of errors dependent on the magnitude of the stars observed. Additional evidence, as it accumulates from time to time, serves to strengthen this opinion. Therefore I have assumed that the magnitude-equation for the catalogue of Groombridge can be determined with a sufficient approximation to the truth by comparison with my standard catalogue corrected for its magnitude-equation, the right-ascensions of Groombridge having been first corrected for terms already treated in the foregoing paragraphs. A summary of results divided into zones is found in Table IV.

In spite of the fact that the precision in determination of time of transit should be decidedly smaller for stars of the declination here concerned than for equatorial stars, the effect of mean magnitude-equation is clearly indicated in each of the zones, and quite satisfactorily so in the mean. The adopted formula of correction for magnitude is

$$-{}^{s}\!\cdot 0107\,(M-3^{m}\!\cdot 5),$$

wherein M denotes the magnitude of an observed star in the scale of a normal uranometry in which the logarithm of the light-ratio is supposed to be 0·36, about that of the historic scale. If the light-ratio is taken as 0·40, the formula of correction becomes $-{}^{s}\!\cdot 0119\,(M-3^{m}\!\cdot 5)$. The column under "Calc." in the last group of Table IV. (general means) is computed from the adopted equation; but it includes also a constant, $-{}^{s}\!\cdot 004$, to eliminate the effect of constant error in the preliminary values of $\Delta\alpha_{\delta}$.

TABLE IV.

Magnitude-equation, $\Delta\alpha_m$.

Zone I. 38° to 47°, decl.

Magn.	No. of Stars.	$\Delta\alpha_m$.
m		s
2·8	12	−·002
4·0	29	+·003
5·0	64	−·032
6·0	46	−·019
7	8	−·087

Zone II. 48° to 57°, decl.

Magn.	No. of Stars.	$\Delta\alpha_m$.
m		s
2·3	11	+·008
4·0	26	−·022
5·0	51	−·026
6·0	36	−·014
7	9	−·002

Zone III. 58° to 63°, decl.

Magn.	No. of Stars.	$\Delta\alpha_m$.
m		s
2·7	10	+·063
4·0	8	−·009
5·0	18	−·023
6·0	30	−·037

Decl., 38° to 63°, Mean.

Magn.	No. of Stars.	$\Delta\alpha_m$.	Calc.
m		s	s
2·5	23	+·018	+·007
4·0	63	−·009	−·009
5·0	133	−·029	−·020
6·0	112	−·023	−·031
7·0	17	−·042	−·041

An entirely critical computation concerning the precision of the right-ascensions of Groombridge is scarcely warranted, because of large and irregular discordances in the observations, and because of the varying number of transit threads (often only one) employed by Groombridge in his observations. However I have arrived at the following rough expression for the p.e. of the right-ascensions:

$$\text{p.e.} = \left\{\sqrt{({}^{s}\!\cdot 018)^2 + \frac{({}^{s}\!\cdot 090)^2}{n}}\right\}\sec\delta,$$

in which n indicates the number of observations for a given star. This is really a low degree of precision, easily accounted for by the small number of transit wires usually employed, and by the unavoidable uncertainty of the constants of reduction.

The comparison of the north polar distances of the Catalogue of Groombridge with the standard offers no point of special difficulty. Table V. contains the result for the differences under the argument, declination, in the sense of declination, Stand.–Groomb. The computed probable errors of the group-values of $\Delta\delta_\delta$ fluctuate between $\pm''{\cdot}06$ and $\pm''{\cdot}04$.

TABLE V.

Observed Values of $\Delta\delta_\delta$.

Mean δ.	No. of Stars.	$\Delta\delta_\delta$.	Curve.	Mean δ.	No. of Stars.	$\Delta\delta_\delta$.	Curve.
°		"	"	°		"	"
86	40	+·09	+·10	55	64	−·02	−·01
80	35	+·27	+·14	50	73	−·03	·00
75	35	−·33	−·18	45	70	+·03	+·04
70	45	−·15	−·16	40	82	+·13	+·08
65	54	−·16	−·09				
60	59	+·02	−·04				

The division errors were determined by the authors from comparison with Newcomb's fundamental Catalogue of the preliminary values of N.P.D. deduced in the two positions of the circle, east and west. The employment of this method appears to have been judicious. The only material differences from the standard catalogue adopted in this paper are found in the vicinity of the pole; and this is as we might have expected. Within 10° from the pole the authors were unable to determine the division error, on account of lack of material; from 10° to 25° from the pole the error could be determined in only one position of the instrument (Int. p. xxxix).

TABLE VI.

Observed Values of $\Delta\delta_\alpha$.

Mean R.A.	No. of Stars.	$\Delta\delta_\alpha$.	Mean R.A.	No. of Stars.	$\Delta\delta_\alpha$.
h		"	h		"
0	62	−·02	12	41	−·06
2	50	−·18	14	43	+·06
4	32	+·20	16	45	+·13
6	40	−·02	18	48	−·01
8	35	−·04	20	64	·00
10	46	−·11	22	63	+·01

For that part of the comparison which has for its argument R.A. we have the results in Table VI. The observed values of $\Delta\delta_\alpha$, in the sense of corrections to the declinations of Groombridge, are small, and they do not indicate a systematic difference from the standard of an appreciable amount. Following my practice in all similar instances I have deduced the following formula of correction for the declinations of Groombridge :—

$$-''{\cdot}03 \sin \alpha - ''{\cdot}00 \cos \alpha.$$

Comparing 1150 pairs of observations taken at random from the star-ledger I find the casual p.e. of a single N.P.D. of Groombridge to be about $\pm''{\cdot}86$. This in connection with the 569 comparisons with the Standard Catalogue (due effect accorded to the weight of the standard for 1810) results in the following expression for the probable error of a catalogue N.P.D. :—

$$\text{p.e} = \sqrt{(\pm''{\cdot}18)^2 + \frac{(''{\cdot}86)^2}{n}},$$

wherein n represents the number of observations. Assuming $\pm''{\cdot}30$ as the p.e. of the unit of weight, the weights in N.P.D. for Groombridge are :

Observations.	Weight.	Observations.	Weight.	Observations.	Weight.
1	·1	5	·5	9	·8
2	·2	6	·6	10	·8
3	·3	7	·6	15	1·0
4	·4	8	·7	20	1·2

Although the zenith-distances of Groombridge depend upon circle-readings, for which only two microscopes were employed, the precision of the resulting N.P.D.'s, indicated in the foregoing, ranks with the best among those of the first half of the nineteenth century—the more important series of fundamental determinations excepted. For instances, this precision is fully twice that which attaches to the original edition of Groombridge's Catalogue; it is more than twice that of Taylor's Madras Catalogue (new reduction by Downing); it is very distinctly superior to that of the first Armagh Catalogue (1840); and, indeed, it seems to be slightly superior to Johnson's observations contained in the first Radcliffe Catalogue (1845).

In R.A. a few of the differences, Stand.-Groom., are large—even larger than could be readily attributed to the large probable error of observation. This is naturally accounted for in the fact that, in addition to the casual probable error of observation, there are important systematic errors peculiar to the observations of individual nights. The unlucky massing of these in the case of certain stars is what one might naturally expect.

The distribution of errors in N.P.D. is remarkably satis-

factory. Only one such difference calls for special remark. The uncorrected difference, Stand.–Groomb., for Groomb. 3709 is $+3''\cdot37$. The authors remark (footnote, p. 95) that Groombridge appears to have considered that 3707 and 3709 lie on the same parallel; for in every instance he has only one circle-reading for the two stars. All nearly contemporary evidence shows that 3709, the following and fainter star of the pair, must have been, in 1810, fully $3''$ north of Groomb. 3707. Consequently it would appear that the circle-readings in question refer exclusively to the brighter and preceding star.

A Simple Method of Obtaining an Approximate Solution of Kepler's Equation. By Arthur A. Rambaut, M.A., D.Sc., F.R.S.

In the *Monthly Notices*, vol. l. p. 301, I have described a method of solving Kepler's equation, viz.

$$m = u - e \sin u,$$

by means of a prolate trochoid.

Six years later the same method was described by Mr. Plummer in the *Monthly Notices*, vol. lvi. p. 317, but no question of priority need arise, as the principle of the method is 200 years older than either of us, being contained in the thirty-first proposition of the first book of Newton's *Principia*.

The object of the present note is to point out another way in which the solution may be very simply effected by the help of the involute of the circle.

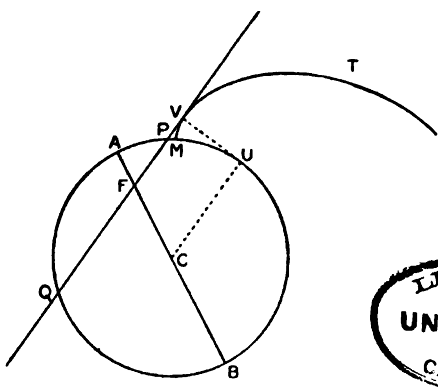


Fig. 1.

Let us take a circle, AMB, fig. 1, with centre C and any radius AC, and lay off the arc AM corresponding to the angle m. From M draw portion of the involute MVT, which can be done

very accurately by mechanical means. Divide AC at F so that $\frac{FC}{AC} = e$. From F draw a tangent to the involute at V cutting the circle in P and Q. Then the angle $AFV = u$.

For the normal to the involute at V touches the circle at U, where the radius CU is parallel to the tangent FV. But

$$AM = AU - MU = AU - VU = AU - FC \sin ACU,$$

or dividing by the radius,

$$m = ACU - \frac{FC}{AC} \sin ACU$$

Hence $ACU = AFV = u$.

Now if the circle be graduated and numbered from 0° at A through P to 180° at B, and also from 0° at B through Q to 180° at A, the arcs AP and BQ may be read off directly, and we have

$$AU = \tfrac{1}{2}(AP + BQ)$$

Hence by taking the mean of the readings of the circle at the points P and Q, where it is cut by the tangent to the involute, we obtain the value of u. It may also be remarked that if u_0 is an approximate value of u thus obtained, and if m_0 be computed from the expression *

$$m_0 = u_0 - e \sin u_0$$

we have

$$\Delta u = \frac{m - m_0}{1 - e \cos u_0}$$

Δu being the correction of the first order required by u_0. But if the radius of the circle be taken as unity we have

$$FV = 1 - e \cos u_0$$

Hence

$$\Delta u = \frac{m - m_0}{FV}$$

Fig. 2 (Plate 2) is a reproduction of a photograph of a very simple instrument constructed on the above principle, by which the value of u may be obtained to within one-tenth of a degree in elliptic orbits of any eccentricity.

For this instrument I have adapted a small setting circle taken from the old "Jones" Meridian Circle of the Radcliffe Observatory. This circle is 5·5 inch in diameter, and is very neatly divided to half-degrees on silver. As the graduations are not numbered, as suggested above, but run continuously through

* Compare Dr. See's paper entitled "A General Method for Facilitating the Solution of Kepler's Equation by Mechanical Means," *Monthly Notices*, vol. lv. p. 425.

MECHANICAL SOLUTION OF KEPLER'S EQUATION. A. A. RAMBAUT.
FIG. 2.

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On Ancient Eclipses. By P. H. Cowell.

One of the most striking features of Mr. Nevill's recent paper (*Monthly Notices*, lxvi. pp. 404–420) is that, whereas I maintain that the ancient eclipses can only be satisfied by one set of formulæ for the configuration of the node, Sun, and Moon, he produces four systems, and states, on p. 415, that they respectively satisfy, out of twelve eclipses, seven or possibly nine, seven or eight, six at least, but possibly eight, and ten. A moment's consideration will show that Mr. Nevill and I must be using the word "satisfy" in different senses. He is evidently more easily satisfied than I am. On p. 416 he regards as satisfactory any value of $\Delta\phi$ less than $2\frac{1}{2}°$; translating this into my language he is satisfied if the tabular latitude of the Moon, corrected for the difference of parallaxes at the moment of apparent conjunction in longitude, is less than $130''$—for shortness I will say if the residual is less than $130''$. Now the whole point of my first paper on eclipses (*Monthly Notices*, lxv. pp. 861–867) is that the residuals can be simultaneously reduced to less than $50''$. Mr. Nevill therefore uses the word "satisfy" with its stringency relaxed in the proportion of $5 : 2$; it is no wonder, therefore, that so vast a number of mutually exclusive systems give him this very moderate amount of satisfaction. The same considerations explain Mr. Nevill's treatment of the eclipse of Utica. On p. 867 (*Monthly Notices*, lxv.) I give as the equation arising from this eclipse

$$+23s_F - 38s_D = +39''$$

where s_F, s_D are the corrections to the secular accelerations of the argument of latitude and mean elongation as adopted in my calculations.

The present tables imply, to those who believe in their accuracy, that $s_F = -4''$; we should then have

$$+23\,(s_F+4'')-38s_D=+131''$$

Therefore I say that because I want residuals less than 50″ the eclipse of Utica is evidence in favour of my formulæ as against the present tables. Mr. Nevill, however, would be satisfied by the new residual. He therefore naturally considers (*Monthly Notices*, lxvi. p. 415) that "the epoch" (of the eclipse of Utica) "is so late that it cannot be regarded as of any value."

Again a very slight inspection of the five equations of condition on p. 867 (*Monthly Notices*, lxv.) will show that they can only be satisfied, in my sense, by small corrections to the secular accelerations adopted by me.

In exhibiting more eclipse calculations, I have had to decide whether to adopt a secular acceleration for the Sun in my formulæ or a secular acceleration of the node contrary to gravitational theory. I have preferred the former course, but I wish it to be clearly understood that the ancient eclipses only afford evidence of the relative movements of the Sun, Moon, and node, and not of the position of the equinox. Mr. Nevill's statement

Lunar Eclipses.

Ref. No.	T.	T^2.	T^3.	g.	ω.	$-\Omega$.	L′.	π'.	L.
				° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″
1	−25·197527	634·92	−15998	248 26 34	118 32 47	189 45 16	350 29 36	236 25 39	177 14 [illegible]
2	−25·187833	634·43	−15980	194 24 7	176 44 49	208 30 17	339 29 1	236 26 38	162 38 [illegible]
3	−25·182991	634·18	−15971	344 59 42	205 49 3	217 52 14	153 47 57	236 27 8	332 56 [illegible]
4	−24·196615	585·48	−14167	161 49 17	7 49 15	325 45 50	24 1 21	238 7 54	203 52 [illegible]
5	−23·214281	538·90	−12510	209 50 12	145 32 4	65 50 6	108 44 2	239 48 15	289 32 [illegible]
6	−23·000838	529·04	−12168	184 27 20	346 59 44	118 41 6	232 49 55	240 10 4	52 45 [illegible]
7	−22·896527	524·25	−12004	281 28 45	253 15 13	320 26 50	28 6 4	240 20 44	214 17 [illegible]
8	−21·809918	475·67	−10374	49 22 29	296 58 34	262 12 21	266 47 23	242 11 48	84 8 [illegible]
9	−21·805057	475·46	−10367	209 2 8	326 9 37	271 36 29	81 47 21	242 12 18	263 35 [illegible]
10	−21·800209	475·25	−10361	2 29 34	355 16 0	280 59 7	256 19 15	242 12 47	76 46 [illegible]
11	−19·992410	399·70	− 7991	121 3 4	48 46 3	177 41 6	178 21 52	245 17 38	352 8 [illegible]
12	−19·987530	399·50	− 7985	289 46 44	78 3 55	187 7 26	354 2 52	24 18 7	180 43 [illegible]
13	−19·982709	399·31	− 7979	70 21 7	107 0 32	196 26 56	167 36 27	245 18 37	340 54 [illegible]
14	−19·726393	389·13	− 7676	343 54 39	205 50 58	332 13 20	35 9 56	245 44 51	217 32 [illegible]
15	−19·398950	376·32	− 7300	359 9 22	11 42 42	245 34 14	303 20 49	246 18 19	125 17 [illegible]
16	−16·747069	280·46	− 4697	72 22 51	92 39 29	334 53 23	12 57 43	250 49 43	190 8 [illegible]
17	−16·666218	277·76	− 4629	134 20 51	218 3 22	131 16 21	43 39 21	250 57 58	221 7 [illegible]
18	−16·651653	277·28	− 4617	244 44 31	305 29 54	159 26 40	208 0 24	250 59 29	30 47 [illegible]
19	−16·637903	276·82	− 4606	326 13 11	28 2 53	186 2 23	343 0 59	251 0 53	168 13 [illegible]

in his footnote to p. 417 (*Monthly Notices*, lxvi.) is perfectly correct; it is true that V − V′ may be altered by about 300″; but in forming the residual V − V′ has to be multiplied by the small quantity that I have called *k*, and the product is generally small. I have therefore substituted for the formulæ on p. 863 (*Monthly Notices*, lxv.) the following:

$$\begin{array}{rlllll} g = & 110^\circ & 19' & 38'' + & 171791\ 5794T & + 49''\cdot 8T^2 + 0''\cdot 050T^3 \\ \omega = & 192 & 7 & 25 + & 2161\ 1516T & - 45\ \cdot 4T^2 - 0\ \cdot 044T^3 \\ -\Omega = & 326 & 43 & 39 + & 696\ 2921T & - 7\ \cdot 6T^2 - 0\ \cdot 007T^3 \\ L' = & 279 & 54 & 29 + & 12960\ 2766T & + 5\ \cdot 2T^2 \\ \pi' = & 279 & 29 & 47 + & 6186T & + 1\ \cdot 6T^2 + 0\ \cdot 012T^3 \end{array}$$

No other formula has been altered; the solar eclipse calculations of this paper are therefore sufficiently explained in my previous paper.

It is an unfortunate fact that in a large number of cases I am unable to agree that the quantities that Mr. Nevill has published in the fourth column of his paper under the heading "Cowell" represent my formulæ. To assist anyone who wishes

Ref. No.	V − L.	V′ − L′.	V − V′ + 180°.	U.	$\frac{d}{dt}$(V − V′).	$\frac{dU}{dt}$.	μ.	Σ = $p+p'-\sigma$.	Δ = Least distance of centres.
1	−17280″	+6628″	+361″	+ 758″	1541″	+155″	916″	2410″	718″
2	− 5042	+7101	−765	+3091	1424	+146	886	2298	3154
3	− 4095	−7286	+105	−2912	1861	−184	1003	2721	2887
4	+ 5358	+4025	+814	+2777	1431	−146	887	2311	2845
5	− 8343	−5421	− 34	−2180	1445	+147	891	2323	2167
6	− 1168	− 951	−454	+2780	1414	−145	885	2273	2721
7	−17969	+3817	+478	+3189	1669	−165	949	2540	3220
8	+13491	+3090	+880	−3022	1773	+176	980	2625	3095
9	− 8386	−2388	+477	+2217	1445	−147	890	2325	2255
10	+ 674	+1811	+495	− 618	1867	+185	1005	2715	665
11	+15862	−6727	+158	+1876	1507	−152	908	2368	1882
12	−17765	+6816	−560	+ 976	1701	+168	958	2563	1025
13	+17624	−7117	+637	− 660	1698	−168	958	2555	595
14	− 5660	+3616	−735	−2619	1865	−184	1002	2734	2678
15	− 1096	+6148	−223	+3407	1869	+185	1005	2722	3412
16	+16777	+6026	+625	+3149	1692	−167	957	2564	3194
17	+12572	+3237	+246	−1306	1477	+149	899	2357	1325
18	−15668	−4987	−640	−1817	1523	−154	914	2384	1872
19	−10624	+7188	+950	−2652	1825	+181	992	2684	2732

to form an independent opinion on this point, I again publish in nearly the same form as in *Monthly Notices*, lxv. p. 866, what I may call the stepping-stones of my calculations, and I publish one calculation *in extenso*, selecting the eclipse of −708 July 17, where I can only believe that Mr. Nevill has made an error. If, therefore, anyone should suspect an error in my calculations, it should be excessively easy to demonstrate its existence.

In the calculations relating to solar eclipses the same reference number is used when more than one eclipse is worked up in connexion with the same record, and small letters are used in addition to the reference number in order to distinguish between the alternatives. Chinese eclipses are marked with capital letters instead of numbers.

T is the time in Julian centuries from 1800 Jan. 0·0 G.M.T. New Style, or 1799 Dec. 20·0 G.M.T. Old Style.

g, ω, $-$ ☊ . L′ . π' are calculated according to the formulæ given in this paper; $L = g + \omega +$ ☊, the Moon's mean longitude.

V−L, V′−L′, are the inequalities of longitude of the Moon and the Sun. The formulæ employed are given in *Monthly Notices*, lxv. pp. 861–7.

V−V′, U are the difference of true geocentric longitude of the Moon and Sun and the geocentric latitude of the Moon.

Ref. No.	Date.	ΔT in units of Julian century + 10⁸ = 0ᵐ·53.	ΔT₁	Semi-duration ΔT₂ in minutes.	G.M.T. of middle of eclipse (tabular).	Observed *minus* tabular time. beginning.	middle.	end.
				m	h m	m	m	m
1	−720 Mar. 19	−23	− 5	111·3	7 35·2	[−85]		
2	−719 Mar. 8	+54	−22	15·9	9 52·4	...	+34	
3	−719 Sept. 1	− 6	−16	66·8	5 53·8	−49		
4	−620 Apr. 21	−57	+20	54·1	14 58·0	−23		
5	−522 July 16	+ 2	+15	86·4	9 25·5	...	+14	
6	−501 Nov. 19	+31	+19	59·9	9 50·8	−29		
7	−490 Apr. 25	−29	+20	42·4	8 21·2	...	+ 6	
8	−382 Dec. 22	−50	+18	55·1	17 36·0	?		
9	−381 June 18	−33	+15	83·7	6 52·6	−21	...	− 8
10	−381 Dec. 12	−27	+ 4	103·4	8 35·3	+ 4		
11	−200 Sept. 22	−10	+12	93·8	5 24·7	−28	...	−34
12	−199 Mar. 19	+33	− 6	104·4	11 26·3	−13		
13	−199 Sept. 11	−37	− 4	107·6	12 55·9	−30	−34	
14	−173 Apr. 30	+39	−15	73·7	12 6·4	− 5	...	+11
15	−140 Jan. 27	+12	−18	42·4	8 22·6	+27		
16	+125 Apr. 5	−37	+19	46·1	7 9·4	+ 3		
17	+133 May 6	−17	+ 9	106·0	9 13·9	...	− 6	
18	+134 Oct. 20	+42	−12	93·8	9 14·6	...	−29	
19	+136 Mar. 5	−52	+15	71·0	13 54·4	...	+10	

$\frac{d}{dt}(V-V'), \frac{du}{dt}$ are the changes of $V-V'$ and U in one millionth of a Julian century or 53 minutes of solar time.

$p-p'$ is the difference of parallax.

The place for which parallactic displacements are calculated is then set down, together with its assumed longitude and latitude; next follow the date and the local mean solar and sidereal times.

v', u' are the parallactic displacements in longitude and latitude calculated for the Sun's place with the difference of parallaxes. The subsequent columns explain themselves or are explained in *Monthly Notices*, lxv. 861–7, and the residual is the difference of apparent latitude at apparent conjunction in longitude, the positive sign indicating that the Moon is apparently south of the Sun. Finally the equation of condition is set down.

The calculations for lunar eclipses begin as in the case of solar eclipses; subsequently μ, $\Sigma = p+p'-\sigma$, Δ are the semi-diameters of the Moon and shadow, and the least distance between their centres.

$\mu = 0{\cdot}273 \times$ Moon's parallax.

$\sigma = 960'' + 16'' \cos g'$; $p' = 9'$

Ref. No.	Observed magnitude.	Tabular magnitude.	Observed *minus* tabular magnitude. (a)	(b)	Observed *minus* tabular magnitude with allowance for increment of Earth's shadow. (a)	(b)	Corresponding corrections to assumed secular acceleration. ″	″
1	total	1·42						
2	3 digits = 0·25	0·02	+0·23					
3	more than half	0·42	+0·09 ?	...	+0·07		−2·4	
4	0·25	0·20	...	+0·05	...	+0·03	...	+1·1
5	0·5	0·59	...	−0·09	...	−0·11	..	−4·4
6	0·25	0·25	...	0·00	...	−0·02	...	−0·8
7	2 digits = 0·17	0·14	...	+0·03	...	+0·01	...	+0·4
8	small	0·26						
9	—	0·54						
10	total	1·52						
11	partial	0·77						
12	total	1·30						
13	total	1·52						
14	7 digits = 0·58	0·53	+0·05	...	+0·03	...	−1·6	
15	3 digits = 0·25	0·16	+0·09	...	+0·07	...	−4·0	
16	0·17	0·17	—	0·00	...	−0·02	...	−1·5
17	total	1·07						
18	[0·33]	0·78	−0·11 ?					
19	0·50	0·48	...	+0·02	...	0·00	...	0·0

Δ = latitude of Moon at conjunction in longitude as inferred from the values of $V-V'+180°$, U, $\frac{d}{dt}(V-V')$, $\frac{du}{dt}$ and diminished by one half per cent., to represent multiplication by the cosine of the inclination of the Moon's orbit.

ΔT = interval from the instant chosen for calculation to the instant of conjunction in longitude.

ΔT_1 = interval from conjunction in longitude to the middle of the eclipse.

ΔT, ΔT_1 are expressed in units of a Julian century $\times 10^{-8}$ $=0.53$ solar minutes

$$\Delta T = 100\,(V-V'+180°) \div \frac{d}{dt}(V-V')$$

$\Delta T_1 = \Delta \div \frac{dU}{dt}$, the sign of ΔT_1 being negative if U and $\frac{dU}{dt}$ are of the same sign. To obtain this formula 100 times squared sine of the inclination of the relative orbit is taken as unity.

ΔT_2 is the semi-duration of the eclipse in solar minutes; the semi-chord of the eclipse is $\sqrt{\{(\Sigma+\mu)^2-\Delta^2\}}$. This is turned into time by dividing by $\frac{d}{dt}(V-V')$, diminishing the quotient by

Solar Eclipses.

Ref. No.	T.	T².	T³.	g.	ω.	−Ω.	L′	π′.	I
				° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′
1a	−29·225902	854·15	−24963	315 30 27	52 45 17	317 50 55	46 12 53	229 34 23	50
1b	−29·154776	850·00	−24782	56 41 48	119 47 17	95 25 30	86 47 57	229 41 39	81
1	−28·613889	818·75	−23428	46 55 40	127 13 5	61 38 33	119 6 7	230 36 50	112
2	−25·615143	656·14	−16807	42 51 29	131 15 23	101 58 53	76 1 37	235 43 0	72
A	−25·074254	628·72	−15765	34 5 31	138 39 13	68 11 41	108 24 25	236 38 15	104
3	**−24·775018**	**613·81**	**−15207**	**233 10 23**	**134 45 28**	**286 50 45**	**78 24 40**	**237 8 48**	**81**
4	**−24·594795**	**604·90**	**−14877**	**231 2 58**	**137 13 52**	**275 35 12**	**89 15 53**	**237 27 13**	**92**
5a	−24·082222	579·95	−13966	29 57 14	334 36 44	187 1 40	182 15 3	238 19 34	177
5	−24·015912	576·76	−13851	352 57 56	12 43 23	315 17 15	49 27 25	238 26 22	50
B	−23·992474	575·64	−13811	17 32 13	153 26 23	0 37 20	173 14 29	238 28 45	170
6	−23·835614	568·14	−13542	350 50 43	15 11 33	304 1 39	60 18 40	238 44 46	62
6a	−23·555862	554·88	−13071	287 59 46	254 45 39	125 8 6	51 34 43	239 13 21	57
7	−22·293794	497·01	−11080	264 35 54	271 54 44	46 16 34	126 54 46	241 22 20	130
8	**−22·022948**	**485·01**	**−10681**	**271 49 57**	**98 0 3**	**210 9 21**	**157 33 35**	**241 50 1**	**150**
9	**−21·964961**	**483·34**	**−10626**	**39 9 44**	**326 3 53**	**283 37 53**	**85 7 6**	**241 53 53**	**81**
10a	**−21·694371**	**467·61**	**−10112**	**32 4 42**	**330 57 1**	**261 5 50**	**106 36 46**	**242 30 46**	**101**
10b	**−21·596051**	**466·39**	**−10072**	**226 19 59**	**140 58 32**	**315 52 28**	**46 9 9**	**242 33 39**	**51**
11	−21·083482	444·51	− 9372	23 22 5	338 17 47	227 18 7	138 59 56	243 26 4	134
C	−20·984025	440·33	− 9240	324 4 35	215 24 29	59 40 29	119 31 17	243 36 14	119
D	−19·864262	394·59	− 7838	73 3 31	98 7 40	65 33 7	111 47 1	245 30 44	105
E	−19·797951	391·96	− 7760	36 33 19	136 14 16	193 48 45	339 1 36	245 37 31	338
12	−16·025461	256·82	− 4116	262 33 23	104 54 19	290 37 57	71 22 12	252 3 35	76

one half per cent., and the unit changed to solar minutes by multiplying by 53.

Hence $\Delta T_2 = 52{\cdot}7 \sqrt{\{(\Sigma+\mu)^2-\Delta^2\}} + \frac{d}{dt}(V - V')$.

The Greenwich mean time of the middle of the eclipse is found by turning $T+\Delta T+\Delta T_1$ from Julian centuries into hours and minutes.

The next three columns give the observed *minus* tabular times; the observed times are taken without change from Professor Newcomb, except that the position of the observers of eclipse No. 8 is considered unknown; the phase observed is sometimes uncertain; that which I have assumed is indicated by the heading.

The next two columns give the observed and tabular magnitudes; the tabular magnitude being calculated from the formula $\frac{1}{2}+\frac{\Sigma-\Delta}{2\mu}$; the difference is entered in column *a* or column *b*, according as a displacement of the Sun relatively to the node in the forward direction would decrease or increase the magnitude of the eclipse; in other words column *a* corresponds to cases

Ref. No.	V−L.	V′−L′.	V−V′.	U.	$\frac{d}{dt}$(V−V′).	$\frac{dU}{dt}$.	$p-p'$.
	″	″	″	″	″	″	″
1*a*	−12853	+ 423	+1840	+1475	1799	+177	3595
1*b*	+15650	−4373	− 639	− 224	1756	−173	3553
1	+13882	−6805	−3068	+ 709	1788	−177	3585
2	+12807	−2493	+1282	+ 743	1804	−178	3601
A	+11070	−5673	+2861	+1367	1828	−181	3626
3	−14178	−2599	−1948	+1269	1497	+150	3304
4	−13705	−3783	+2423	+1432	1490	+150	3298
5*a*	+ 9414	−6141	−1410	+2195	1833	+181	3635
5	− 2471	+1116	− 188	+1590	1875	+185	3672
B	+ 6435	−6698	+2740	+2347	1857	−184	3659
6	− 2758	− 196	+3555	+1670	1873	+185	3670
6*a*	−17280	+ 952	+3524	+ 626	1696	−167	3495
7	−17124	−6569	+1403	+2644	1599	−159	3408
8	−17330	−7259	−2447	+1486	1625	+162	3437
9	+11803	−2812	+1933	+2669	1816	+179	3613
10*a*	+10040	−4982	−1831	+1772	1835	+181	3631
10*b*	−13237	+2012	+3775	+1213	1479	+149	3283
11	+ 7780	−6998	−1913	+1110	1850	+182	3650
C	−10147	−5943	−3166	+1185	1823	−180	3624
D	+17981	−5157	+1001	+1248	1690	−167	3491
E	+10254	+7223	+2865	+1225	1818	−180	3622
12	−17967	+ 84	+1602	+ 805	1594	+159	3396

when the Moon is partially eclipsed on its south limb at the ascending node or on its north limb at the descending node, and column *b* to the two remaining cases.

In this paper I will begin with the discussion of the lunar eclipses first.

An error of 1″ in the secular acceleration of the mean elongation will produce an error of $T^2 \div 30$ minutes in the tabular time, a quantity that varies from 21 minutes for the first eclipse to 9 minutes for the last eclipse. The column of discordances for the middle of the eclipse is satisfactory; the other columns would indicate that the secular acceleration of the mean elongation requires an increase of less than one second, but this correction is diminished if the radius of the shadow be increased by two per cent. for the Earth's atmosphere. The result for the first eclipse may fairly be rejected, as greatly discordant from the others. The probable error seems to be about 2″ for the secular acceleration from each observed time, and the mean result is a correction of about $+0''\cdot5$ to the value $+6''\cdot8$ assumed in my formulæ, with a probable error of less than $\pm 0''\cdot5$.

Ref. No.	Place.	Lat. N.	Long. E.	Date.	Local Mean Time in Degrees.	λ = Local Sidereal Time in Degrees.	v'.
1a	Babylon	32° 26′	44° 13′	−1123 May 18	18°·819	65°·034	+538 + 931 − 120 = +13[illegible]
1b	„	32 26	44 13	−1116 June 28	334·593	61·392	+ 59 − 1176 − 70 = −11[illegible]
1	„	32 26	44 13	−1062 July 31	297·756	56·858	−355 − 2518 − 13 = −[illegible]
2	Nineveh	36 24	43 0	− 762 June 15	7·693	83·720	+218 + 405 − 44 = + 5[illegible]
A	Heeng-yang	34 12	109 3	− 708 July 17	63·204	171·611	−238 + 2598 + 126 = +24[illegible]
3	Nineveh	36 24	43 0	− 678 June 17	305·143	23·554	+168 − 2064 − 111 = −[illegible]
4	Susa	32 6	48 18	− 660 June 27	88·845	178·110	+ 22 + 2675 + 119 = +[illegible]
5a	Larissa	36 6	43 13	− 609 Sept. 30	346·139	168·390	−864 − 592 + 24 = −14[illegible]
5	„	36 6	43 13	− 602 May 18	336·329	25·786	+564 − 1155 − 122 = − 71[illegible]
B	Heeng-yang	34 12	109 3	− 600 Sept. 20	68·424	241·665	−820 + 2728 − 102 = +18[illegible]
6	Iconium	37 48	32 24	− 584 May 28	103·914	164·225	+450 + 2695 + 86 = +3[illegible]
6a	„	37 48	32 24	− 556 May 19	82·962	134·541	+534 + 2624 + 13 = +31[illegible]
7	Athens	37 56	23 38	− 430 Aug. 3	86·327	213·240	−485 + 2573 + 42 = +21[illegible]
8	„	37 56	23 38	− 403 Sept. 3	320·381	117·941	−774 − 1584 + 115 = −[illegible]
9	Rome	41 54	12 29	− 399 June 21	120·296	205·414	+ 96 + 2205 + 107 = +[illegible]
10a	Thebes	38 22	23 20	− 363 July 13	329·054	75·667	−239 − 1845 + 2 = −1[illegible]
10b	„	38 22	23 20	− 360 May 12	108·734	154·886	+563 + 2342 + 40 = +[illegible]
11	Syracuse	37 3	15 16	− 309 Aug. 15	310·449	89·448	−648 − 2061 + 89 = −[illegible]
C	Heeng-yang	34 12	109 3	− 299 July 26	284·325	43·846	−383 − 2760 − 40 = −31[illegible]
D	„	34 12	109 3	− 187 July 17	48·012	159·796	−275 + 2102 + 122 = +19[illegible]
E	„	34 12	109 3	− 180 Mar. 4	51·351	30·378	+775 + 2176 − 25 = +29[illegible]
12	Utica	37 10	10 0	+ 197 June 3	23·311	94·681	+263 + 1025 − 27 = +12[illegible]

Coming to the magnitudes, the material is greatly diminished in quantity by the fact that total eclipses are useless. The second eclipse is distinctly discordant, and so is the eighteenth, in the opposite direction, even when two thirds is taken as the observed magnitude instead of one third. Both are rejected, though the admission of both would make little difference to the result.

The tabular magnitudes were calculated without any allowance for the increment of the shadow due to the Earth's atmosphere. The most prominent fact about the differences "observed *minus* tabular" is that the observations are good enough to indicate an approximation to the accepted modern correction of two per cent. Two per cent. increment of the shadow implies an increment of 0·025 to the magnitude. In the concluding columns of the calculations a correction of 0·02 is applied. The differences "observed *minus* tabular magnitude" are then transformed into corrections to assumed secular acceleration by the factor $214 \div T^2$. The nine corrections so obtained have a range of $5''\cdot5$. The probable

Ref. No.	u'	$\frac{dv'}{dt}$.	$\frac{du'}{dt}$.	$\frac{d}{dt}(V - V' - v')$ = denom. of k.	$-\frac{d}{dt}(U-u')$ = num. of k.	k.	Residual $= k(V-V'-v') - (U-u')$.
1*a*	+1763 − 1111 = + 652″	+632 + 11 = +643″	−119″	1156″	+296″	+0·256	−697″
1*b*	+1743 − 1064 = + 679	+601 + 25 = +626	−134	1130	− 39	−0·034	+884
1	+1759 − 1024 = + 735	+329 + 30 = +359	−154	1429	− 23	−0·016	+ 29
2	+1955 − 1163 = + 792	+630 + 26 = +656	− 29	1148	−149	−0·130	− 42
A	+1865 − 177 = +1688	+281 − 4 = +277	+275	1551	−456	−0·294	+211
3	+1794 − 429 = +1365	+343 + 5 = +348	−226	1149	+376	+0·327	+115
4	+1604 − 37 = +1567	+ 1 + 2 = + 3	+259	1487	−109	−0·073	+163
5*a*	+1960 − 239 = +1721	+632 − 28 = +604	+268	1229	− 87	−0·071	−476
5	+1980 − 521 = +1459	+596 − 7 = +589	−248	1286	+433	+0·337	+ 46
B	+1882 + 1074 = +2956	+224 − 18 = +206	+133	1651	−317	−0·192	+429
6	+2059 − 318 = +1741	−154 + 20 = −134	+259	2007	− 74	−0·037	+ 59
6*a*	+1961 − 794 = +1167	+ 77 + 27 = +104	+179	1592	−346	−0·217	+464
7	+1918 + 594 = +2512	+ 19 − 24 = − 5	+208	1604	−367	−0·229	+ 34
8	+1934 − 965 = + 969	+472 − 2 = +470	+118	1155	+ 44	+0·038	−525
9	+2208 + 465 = +2673	−305 − 9 = −314	+225	2130	− 46	−0·022	(+ 14)
10*a*	+2063 − 1110 = + 953	+545 + 28 = +573	− 65	1262	+246	+0·195	−868
10*b*	+1865 − 440 = +1425	−177 + 23 = −154	+216	1633	− 67	−0·041	+178
11	+2013 − 1172 = + 841	+431 + 19 = +450	− 3	1400	+185	+0·132	−177
C	+1864 − 836 = +1028	+181 + 28 = +209	−200	1614	+ 20	+0·012	−157
D	+1796 − 401 = +1395	+413 − 0 = +413	+250	1277	−417	−0·326	+456
E	+1864 − 609 = +1255	+429 − 28 = +401	−239	1417	+ 59	+0·042	+ 27
12	+1879 − 1083 = + 796	+546 + 25 = +571	+ 20	1023	+139	+0·136	+ 37

error is about $\pm 1''\cdot 3$ for a single determination (corresponding to about $\pm 0\cdot 03$ in the observed magnitude) and for a mean of nine determinations we have a correction $-1''\cdot 5 \pm 0''\cdot 5$ to the value $+4''\cdot 1$ that has been adopted. The value deduced from lunar eclipses is therefore

$$+2''\cdot 6 \pm 0''\cdot 5$$

If a correction to a quantity that we know exists is obtained with a probable error one fifth part of itself, that correction is deemed well established. It is, of course, different when the existence of the quantity is in dispute. Hence it is that from the first I have admitted that the lunar eclipses are not by themselves sufficient to establish either an acceleration for the Sun or an unexpected secular acceleration for the node. But the result here obtained at least demands the examination of other evidence, such as solar eclipses, to see whether it can be confirmed.

I now come to the solar eclipses. I have first of all a few additional remarks to make about the geometry of these eclipses. In many cases the central lines, according to the present tables,

Equation of Condition.

1a	$+76(s_{\mathrm{F}}-s_{\mathrm{D}})$	$-143s_{\mathrm{D}}$	$=-697''$	} −1062 adopted as date.
1b	−76	− 47	+884	
1	−73	− 60	+ 29	
2	−59	+ 26	− 42	
A	−56	+129	+211	Chinese.
3	+55	−146	+115	
4	+54	+ 98	+163	
5a	+52	+ 93	−476	} −602 adopted as date.
5	+52	−142	+ 46	
B	−51	+ 59	+429	Chinese.
6	+51	+ 72	+ 59	} −584 adopted as date.
6a	−50	+ 70	+464	
7	−45	+ 69	+ 34	
8	+43	+ 25	−525	
9	+43	+ 54	(+ 14)	Sun already set.
10a	+42	− 49	−868	} Neither date.
10b	+42	+ 61	+178	
11	+40	− 19	−177	
C	−39	− 44	−157	Chinese.
D	−35	+ 93	+456	"
E	−35	− 51	+ 27	"
12	+23	− 12	+ 37	

pass two or three hundred miles away from the place naturally indicated by the record. Now no admissible alterations of the tables—that is to say, alterations consistent with the observations of the last century—will produce changes of the required magnitude except changes to the secular terms of the elongation and argument of latitude. Hence every geometrical possibility is exhausted by assuming these two unknown quantities. On the other hand, it is wrong to assume that one of these quantities is theoretically zero, for facts must be examined first, and theories made later. If the theory is right, the facts will ultimately support it. Therefore, as long as it is a question of altering the central lines by two or three hundred miles, two unknown quantities are alone admissible. It turns out that these two unknown quantities suffice to reduce the residuals (or differences of latitude at apparent conjunction in longitude) to less than 50″. Further than this I cannot go, for directly it becomes a question of small corrections there is a large choice of possible alterations to the tables competent to produce them. The mean motions may be altered by 10″ or 15″ a century, but not more; the secular term in the lunar perigee may need a small correction; and of course supplementary small corrections may be given to the two principal unknown quantities.

Any formula put forward as satisfying ancient eclipses will still satisfy them if modified by the addition of

$$\lambda(25T+T^2)$$

for this quantity is not large for the epochs of the eclipses. Modern observations will ultimately settle the values of λ for the two formulæ for D and F respectively; all that can be said at present is that λ is less than 0″·5. This consideration will not

Full Calculations for the Eclipse of −708 *July* 17 *at Heeng-yang.*

$$T = -25{\cdot}074254 \qquad T^2 = 628{\cdot}72 \qquad T^3 = -15765$$

Precept.	g	ω	$-\Omega$	L'	ϖ'
T × last 4 figs. of centennial motion ...	− 145 280″	− 38 013″	− 73 242″	− 69 355″	−155 109″
T × rest of centennial motion	−43075 311 689	−541 854 629	−174 516 808	− 153°·144	...
Integral number of revolutions	+43075 152 000	+541 728 000	+174 960 000	...	...
Secular term ...	+ 31 310	− 28 544	− 4 778	+ 3 269″	+ 1 006
Cube term ...	− 788	+ 694	+ 110	...	− 189
Sum	− 76° 14′ 7″	− 53° 28′ 12″	+101° 28′ 2″	−171° 30′ 4″	− 42° 51′ 32″
Add value at 1800·0 ...	34° 5′ 31″	138° 39′ 13″	68° 11′ 41″	108° 24′ 25″	236° 38′ 15″

diminish the slight discordance that there is between the mean result of the lunar eclipses and the result of the solar eclipses, but may possibly diminish the difficulty due to the observations from 1750 to 1800.

The value of the Sun observations in their present state for the period 1750 to 1800 is not great; possibly they are capable of improvement on re-reduction; at present, however, they fail to stand the only test that I can apply: they give (see Newcomb's Astronomical Constants, p. 22) a wholly impossible mass of *Venus*, although the period of the *Venus* perturbations is such as to put systematic errors out of the question. The systematic mean error for the same period may easily be large. How accurately could the clocks of those days carry on the clock error from noon to the mean clock star at about 10 P.M.? How large was the diurnal inequality in level before it was recognised as necessary to keep the shutters closed in the daytime? Again,

Hence $F = 172° 44' 44''$, $L = 104° 33' 3''$, $D = 356° 8' 38''$ $-g' = 128° 13' 50''$.

Inequalities of Longitude.

Argument. Symbolic.	Argument. Numerical.	Coefficient.	Inequality from MS. Table.
	°	$''$	$''$
g	34·092	22640	+ 12 690
$-g+2D$	318·20	4586	− 3 056
$2D$	352·29	2370	− 318
$2g$	68·2	769	+ 714
$-g'$	128·2	669	+ 526
$-2F$	14·5	412	+ 104
$-2g+2D$	284·1	212	− 206
$-g-g'+2D$	86·4	206	+ 206
$g+2D$	26·4	192	+ 85
$-g'+2D$	120·5	165	+ 142
$g-g'$	162·3	148	+ 45
$-D$	3·9	125	+ 9
$-g-g'$	94·1	110	+ 110
$-2F+2D$	7	55	+ 7
$-g-2F$	340	45	− 15
$g-2F$	49	40	+ 30
$-g+4D$	310	38	− 29
$3g$	102	36	+ 35
$-2g+4D$	276	31	− 31
$g-g'-2D$	170	29	+ 5
$-g'-2D$	136	24	+ 17
		Sum =	+ 11 070

are we entitled to say that there are no unknown long-period terms in the motion of the Sun when we know that such terms exist in the case of the Moon? For these reasons I prefer the hypothesis of a secular acceleration of the Sun to that of a secular acceleration of the node contrary to gravitational theory.

In exhibiting the equations of condition for the solar eclipses in my first paper I gave linear equations between s_F and s_D, the corrections required by the secular terms of the argument of latitude and the elongation. Since working up the lunar eclipses it is preferable to take $s_F - s_D$ and s_D as the two fundamental quantities, because these are the quantities determined by the magnitudes and times of the lunar eclipses respectively. The coefficient of $s_F - s_D$ is $\pm 0{\cdot}0895\ T^2$, for the ascending or descending node respectively, and the coefficient of s_D is $(\pm 0{\cdot}0895 - k)T^2$.

Inequalities of Latitude.

Argument. Symbolic.	Argument. Numerical.	Coefficient.	Inequality from MS. Table.
F	$172^\circ{\cdot}746$	$18461''$	$+2331''$
$g+F$	$206{\cdot}84$	1010	-456
$g-F$	$221{\cdot}34$	1000	-660
$-F+2D$	$179{\cdot}6$	624	$+4$
$-g+F+2D$	$130{\cdot}9$	199	$+150$
$-g-F+2D$	$145{\cdot}5$	167	$+94$
$F+2D$	$165{\cdot}0$	117	$+30$
$2g+F$	241	62	-54
$g-F+2D$	214	33	-18
$2g-F$	255	32	-31
$-g'-F+2D$	308	30	-24
$-2g-F+2D$	111	16	$+15$
$g+F+2D$	199	15	-5
$-g'+F-2D$	309	12	-9
		Sum =	$+1367$

Parallax &c. (for numerical arguments, see inequalities of longitude).

$$p = 3423'' + 187'' \cos g + 34'' \cos (2D - g) + 28'' \cos 2D + 10'' \cos 2g$$

$$= 3423 + 155 + 25 + 28 + 4 = 3635''$$

$$p - p' = 3626''$$

$$\frac{d}{dt}(V - V') = 1632'' + 227'' \cos g + 13'' \cos 2g - 5 \cos g'$$

$$= 1632 + 188 + 5 + 3 = 1828''$$

$$-\frac{dU}{dt} = 163'' + 20'' \cos g + 2'' \cos 2g = 163 + 17 + 1 = 181''$$

Equation of centre of Sun.

$$e_1' = 7324'' \sin g' = -7855 \text{ product } -5753''$$
$$e_2' = 82 \sin 2g' = +97 \quad ,, \quad +80$$
$$\text{Sum } -5673$$
$$V-V' = +2861$$

$\sin \epsilon = 4035$ $\cos \epsilon = 9151$

Latitude $\lambda = 34^\circ\ 12'$ $\sin \lambda = 5621$ $\cos \lambda = 8271$

G.M.T. $314^\circ{\cdot}154$ Longitude $109^\circ{\cdot}050$

Local Mean Solar Time $63^\circ{\cdot}204$ $L' = 108^\circ{\cdot}407$

Local Sidereal Time h $171{\cdot}611$ $V' = 106{\cdot}831$

$h - V' = 64^\circ{\cdot}780$ $h + V' = 278^\circ{\cdot}442$

Parallactic Displacements.

$(p-p') \sin \lambda \sin \epsilon$ 822 ; $\cos V'$ -290 product -238

$(p-p') \cos \lambda \cos^2 \frac{\epsilon}{2}$ 2872 ; $\sin (h-V') + 9047$,, $+2598$

$(p-p') \cos \lambda \sin^2 \frac{\epsilon}{2}$ 127 ; $-\sin (h+V') + 989$,, $+126$

$$v' = \text{sum} = +2486''$$

$(p-p') \sin \lambda \cos \epsilon$ $= 1865$

$(p-p') \cos \lambda \sin \epsilon$ 1210 ; $-\sin h - 1459$ product -177

$$u' = \text{sum} = +1688''$$

$0{\cdot}2295 \times (p-p') \cos \lambda \cos^2 \frac{\epsilon}{2}$ 659; $\cos (h-V') + 426$ product $+281$

$0{\cdot}2307 \times (p-p') \cos \lambda \sin^2 \frac{\epsilon}{2}$ 29 ; $-\cos (h+V') - 15$,, -4

$$\frac{dv'}{dt} = \text{sum} = +277''$$

$0{\cdot}2301 \times (p-p') \cos \lambda \sin \epsilon$ 278; $-\cos h + 989$

$$\frac{du'}{dt} = \text{product} = +275''$$

Hence

$$V - V' - v' = +375'' \qquad U - u' = -321''$$

$$\frac{d}{dt}(V - V' - v') = +1551'' \qquad \frac{d}{dt}(U - u') = -456''$$

$$k = -0{\cdot}294$$

$$\text{Residual } = k(V - V' - v') - (U - u') = +211''$$

The Eclipse at Babylon.—Equations of condition are given for the eclipses of -1123, -1116, and -1062; and in *Monthly Notices*, lxv. p. 867, the equation of condition for -1069 with slightly different formulæ is seen to be

$$74(s_F - s_D) - 189 s_D = +655''$$

From these alternatives I select -1062 as the date of the eclipse. As to the meaning of Sivan, the equation

$$26 \text{ Sivan} = \text{July } 31$$

must be accepted, or the record must not be interpreted to mean that there was a total solar eclipse at Babylon.

The Eclipse of Nineveh.—In addition to having been recorded at Nineveh, it is clear that this eclipse was seen by the prophet Amos (see Amos viii. 9).

I have taken as the place for calculation lat. 32° 40′, long. 35° 21′.

Calculating as in other cases, I obtain

$$\begin{array}{llll}
v' = +198 + 37 - 62 & = +173'' & V - V' - v & = +1109'' \\
u' = +1778 - 1187 & = +591 & U - u' & = +152 \\
\dfrac{dv'}{dt} = +666 + 26 & = +692 & \dfrac{d}{dt}(V - V' - v') & = +1112 \\
\dfrac{du'}{dt} & = -68 & \dfrac{d}{dt}(U - u') & = -110
\end{array}$$

Hence $k = -0''{\cdot}100$, and the residual is $-263''$.

The central line therefore passed a long way to the north of Samaria according to my formulæ.

The Chinese Eclipses.—Five eclipses have been calculated for Heeng-yang. The equations of condition are

$$\begin{aligned}
-56\,(s_F - s_D) + 129\,s_D &= +211'' \\
-51\,(s_F - s_D) + 59\,s_D &= +429 \\
-39\,(s_F - s_D) - 44\,s_D &= -157 \\
-35\,(s_F - s_D) + 93\,s_D &= +456 \\
-35\,(s_F - s_D) - 51\,s_D &= +27
\end{aligned}$$

I cannot find any alteration of the formulæ or of the place of observation that will make these five eclipses all total at the same place. Our information about them is evidently deficient. They appear to be valueless, and they neither support nor conflict with any particular formulæ.

The Eclipse of Esar-haddon.—The record is perhaps satisfied if the central line intersects the line of communications between Nineveh and the Assyrian king who had gone to Egypt. The positive residual $+115''$ given by my formulæ for Nineveh shows that the central line passed south of Nineveh. I therefore do not think that this eclipse conflicts in any way with my formulæ.

The Eclipse of Susa.—This eclipse is considered by Mr. Nevill in *M.N.* lxvi. p. 411; it is not, however, quite apparent why he has labelled the eclipse "of Susa," for I am informed that the tablet was found at Nineveh; and the words quoted by Mr. Nevill contain no reference to Susa. I have, however, calculated for Susa, and I find that the central line passed considerably to the south. The record is very vague, and the details unintelligible. The Sun, as Mr. Nevill points out, cannot be troubled for three days in an eclipse.

The Eclipse of Archilochus.—My formulæ supply a reasonable explanation of how it was that Archilochus saw a total eclipse. On the other hand, many other formulæ would do as much. Mr. Nevill says we have a choice of seven eclipses. Professor Millosevich excludes three of these and leaves four. In addition Archilochus is known to have lived in Paros as well as Thasos. I therefore withdraw the eclipse of Archilochus, merely congratulating myself that my formulæ do not compel me to suppose that by some curious coincidence the eclipse took place just as Archilochus had got half-way between Paros and Thasos.

The Eclipse of Larissa.—Equations of condition are given for -609 and -602. The latter date fits in with my formulæ.

Mr. Nevill's historical note on this eclipse is most valuable.

The Eclipse of Thales.—Equations of condition are given for -584 and -556; for the former date my formulæ make the central line pass very slightly to the south of Iconium at about $7^h\ 4^m$, or about three minutes before sunset. There is of course an uncertainty as to the exact position of the battlefield; but this is compensated by the fact that formulæ which throw the central line much further south make it miss the mainland altogether.

If an eclipse be total just before sunset, the parts of the Sun that are first uncovered by the Moon are roughly the same as those that first disappear below the horizon. The phenomenon may thus be somewhat prolonged and to that extent more terrifying.

The Eclipse of Thucydides.—The careful language of Thucydides may advantageously be compared with his description of a partial eclipse that occurred seven years later (Thuc. iv. 52). Thucydides clearly does not describe partial eclipses as if they were total or annular. But in any case Thucydides would never have imagined the appearance of certain of the stars. He saw it. Now in *A.N.* 3682 we read that the path of this eclipse

"did not come within 500 miles of Greece." These 500 miles are, I believe, to be measured in a north-easterly direction. What does Professor Newcomb think that Thucydides was doing in the middle of the Black Sea? It is reasonable to impose the condition that Thucydides was not at any rate further off than the Bosphorus, and this limitation, to anyone who believes that the present tables correctly represent the positions of the Sun and the node, will necessitate the reduction of the secular acceleration of the Moon to its theoretical value. I however see no reason to doubt that Thucydides was in Athens, as my formulæ would make him. We know he was in Athens the following summer, when he caught the plague. He tells us on another occasion when he went on foreign service; his silence presumes that he was not on foreign service in the first year of the war. But he might, it is said, have gone to look after his estates in Thrace. If so, I do not think that he would have been so careful to explain that he was aware at this very time of the exceptional importance of the war.

"Thucydides, an Athenian, wrote the history of the war in which the Peloponnesians and the Athenians fought against one another. He began to write when they first took up arms, believing that it would be great and memorable above any previous war; for he argued that both States were then at the full height of their military power, and he saw the rest of the Hellenes either siding or intending to side with one or other of them. No movement ever stirred Hellas more deeply than this; it was shared by many of the Barbarians, and might be said even to affect the world at large." (Jowett.)

And, again, if he saw stars in the North Ægean, and if stars were not seen at Athens, he would very likely have known it.

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Moreover, the same accuracy is not to be expected of an historian who ranges over so vast a field as Plutarch as from a specialist who writes about a shorter period. On the other hand, Plutarch fills in details. He describes not only the eclipse, but the effect produced by the darkness.

The Eclipse of Agathocles.—In a footnote in *Monthly Notices*, lxvi. p. 417, Mr. Nevill points out a distinction between my two hypotheses: (i.) assigning a secular acceleration to the node different from that required by theory; (ii.) assigning a secular acceleration to the Sun. It is perfectly true that at the same tabular time the two values of the difference of longitude will differ roughly by

$$0''\cdot 4 \ T^2 \cos g$$

In forming the residual, however, this quantity has to be multiplied by "*k*." The product is often negligible, but in this case it happens that it is as much as 40″. My first hypothesis, therefore, requires that Agathocles should have got to a distance of at least eighty miles from Syracuse, and my second to a distance of at least 120 miles. Both distances are perfectly possible. The account says that he only got away from the Carthaginians after dark. He was therefore in full flight for a whole day—possibly fifteen hours. Grote states that "during the night he made considerable way." In *Nature* (1906 November 2) I have discussed the historical evidence. Agathocles appears to have left Syracuse early on August 14 with a favourable wind, and there are many indications that he went northwards.

The Eclipse of Utica.—My formulæ make the eclipse of +197 total at Utica, and supply a commentary upon the words of Tertullian that does not lose its force even if it be proved that Tertullian wrote twelve years later.

Professor Newcomb says that I ignore Tertullian's "pœne." I regard my eclipse papers as proving empirical corrections removing errors from the present tables of the order 4″ T^2. As we cannot replace 4″ T^2 in the formulæ by −100″ T, because such a correction is incompatible with modern observations, it follows that there is no geometrical alternative to correcting the secular terms until the errors of the present tables have been reduced from the order 4″ T^2 to, say, the order 0″·4 T^2. When this degree of accuracy is reached small corrections may be applied, either to the secular terms or mean motions; in fact, we get as many arbitrary quantities as equations of condition; and hence I consider that my formulæ will only give eclipse tracks correctly to within fifty miles. I maintain that they are free from errors of 200 to 300 miles, and that the present tables are not free from such errors. Therefore, if Professor Newcomb likes, he may take the word "pœne" to mean that the central line missed Utica by a few miles. There is the further obvious alternative that "pœne" merely corresponds with the fact that there is not black darkness even on the central line of a total eclipse.

I understand Professor Newcomb to suggest (*Monthly Notices*, lxvi. p. 470) that because Airy and others deduced erroneous conclusions from ancient eclipses, therefore my conclusions will, in all probability, turn out also to be unsound. I will therefore conclude by examining the basis of Airy's conclusions. His last paper, entirely contradicting his previous paper in the *Transactions of the Royal Society* for 1853, is published in the *Memoirs, R.A.S.*, vol. xxvi. Inasmuch as his conclusion is that Hansen's tables represent the ancient eclipses that he examined, he has this in common with me, that his formulæ, as well as mine, will satisfy a century of modern observations; the same cannot be said of Oppolzer and Ginzel. Airy, however, only uses three eclipses. One of these three is the eclipse of Agathocles, where the uncertainty in the position of Agathocles causes the eclipse to satisfy nearly any formulæ; another eclipse is that of Thales, which is well known to be satisfied by Hansen's tables; and the third eclipse is that of Larissa, to which Airy assigns an impossible date. Inferences from eclipses, in view of the want of absolute precision in the records, depend upon the production of an overwhelming degree of coincidence. Airy's investigations, in reality, deduce a result from Thales, and show, as they were nearly certain to do, that the central line for Agathocles comes within one day's journey of Syracuse; and the whole degree of confirmation lies in the fact of the supposed agreement of the eclipse of Larissa, for which he has taken a wrong date. In no previous attempt to explain ancient eclipses has it ever happened that confirmation has been obtained from other eclipses. But in my case the eclipse at Babylon, the lunar eclipses, the eclipses of Thales and Larissa have all supported the explanation at which I had previously arrived from other evidence, viz. the eclipses of Nineveh, Archilochus, Thucydides, Agathocles, and Tertullian.

By what right is Airy taken as the basis for an argument that, if Airy was wrong, others too will probably be wrong? What portion of Airy's "grand labours" on the Moon, to quote a recent phrase of Lord Crawford's, survives to the present day? Is there any correct result relating to the Moon connected with his name? His measurement of the constants is most inaccurate. With a hundred years' observations at his disposal, he failed to detect any one of three short-period errors with coefficients exceeding 3″ in his tabular longitudes; his analysis is based upon the two erroneous assumptions that his adopted solar terms are right, and that the errors of his tables depend on the position of the node. On both these points it was Mr. Nevill who got into the right path: it was he who first showed that the eccentricity of the Moon could not be determined correctly as long as certain errors in the solar terms were ignored (*Mem. R.A.S.*, vol. xlviii. pp. 315, 318), and it was Mr. Nevill who first showed that the defect of the tables was largely due to the short-period perturbations produced by the planets.

The Eclipse of Archilochus.

(*Extract from a letter from Professor E. Millosevich.*)

In the important paper on ancient eclipses of the Sun, by Mr. Nevill, *Monthly Notices*, vol. lxvi. No. 7, speaking (on p. 410) of the eclipse of Archilochus, identified by Oppolzer, by myself, and by Cowell with that of −647 April 6, total at Thasos, he says, "But this is considerably later than the date usually assigned to this poet."

The age in which Archilochus lived is determined by the fact that he mentions King Gyges of Lydia, and the catastrophe of Magnesia which occurred towards the *end* of the reign of Gyges or a *little later*. Gugu (Gyges) is mentioned as a contemporary in an inscription of the Assyrian king Assur-bani-pal, who reigned *circa* 668 to 626 B.C. The inscription is later than B.C. 662. Archilochus therefore cannot have lived before the middle of the seventh century. This is the opinion of Julius Beloch, the eminent historian of ancient Greece, from whom I had the above information.

Star Reductions. By W. Ernest Cooke, B.A.

The reduction of star places from apparent to mean positions, and *vice versa*, occupies such a large portion of observatory routine that no apology is needed for bringing before the notice of the R.A.S. a new method of attacking this troublesome matter.

If the formulæ of reduction (*Nautical Almanac*, 1906, p. 305) be examined it will be found that they may conveniently be divided into two parts :

(1) Functions of ☉ and L, and therefore of t

(2) „ „ ☊

and a few terms which may for most work be considered as negligible.

I propose that

(3) Tables be formed, giving the values of

$$A^\circ a + B^\circ b + C^\circ c + D^\circ d = K_a \text{ say}$$

and
$$A^\circ a' + B^\circ b' + C^\circ c' + D^\circ d' = K_\delta \text{ „}$$

for each degree of N.P.D. and every 10^m of R.A., and for each tenth day throughout the year, commencing with $t = 0$ or $L = 280^\circ$.

In this case C° and D° are computed with the elimination of terms in ☊ and 2☊, also ☾, &c.

I shall refer to these as the *Standard Tables*.

(4) In addition, an annual table is required, giving N_α and N_δ the missing terms in Ω and $2\,\Omega$, and this is computed as follows:

Quantities x and y are tabulated for each 5° of Ω giving

$$x = -\ {\cdot}342 \sin \Omega + {\cdot}004 \sin 2\,\Omega$$

$$y = -9{\cdot}21 \cos \Omega + {\cdot}09 \cos 2\,\Omega$$

Then $\qquad N_\alpha = cx + dy \qquad N_\delta = c'x + d'y$

(5) The reduction for any star is then simply the sum of the two quantities K and N, which can be taken from the tables by simple interpolation.

(6) The preparation of the Standard Tables is a rather lengthy undertaking, but the tables, when computed, will be practically correct for centuries. It will not be found so arduous as it might at first appear, because there is so much numerical repetition, with opposite signs in the different quadrants, and interpolation can be freely used.

(7) The annual table also is not a very serious affair. It must be remembered that Ω only changes about 20° annually, and five values of t (0, 100, 200, 300, 400) are ample. In fact for many purposes two will suffice. The changes are so slight that every 2^h in R.A. and every 5° or even 10° in N.P.D. will be found sufficient for the main computation.

(8) As a matter of practice many observatories will find the computation of the annual table (even if it is not undertaken as a regular habit by the compilers of National Ephemerides) a very simple matter; for their observations during any one year may extend over only a few degrees in declination.

(9) Take my own case. The transit work of the Perth Observatory is at present limited to the zone between -31° and $-41^\circ\ \delta$. I have prepared Standard Tables for -36°, and the variations in every case for an increase and decrease of 5° in N.P.D., computed with a simple differential formula. These tables are good for all time.

Then for each year I have to compute:

$$N_\alpha = cx + dy$$
$$I_\alpha = c_i x + d_i y$$
$$D_\alpha = c_d x + d_d y$$
$$N_\delta = c'x + d'y$$

where I_α and D_α mean the change in the annual value for an increase or decrease of 5° in N.P.D.

c and d are the ordinary values for 36°.

c_i, c_d &c. are the variation in c and d for an increase or decrease of 5° in N.P.D., &c.

I compute for 0^h, 2^h, 4^h, &c., and interpolate to half hours, and find that five values of t (0, 100, 200, 300, and 400 days) are more than sufficient.

Values of A°, B°, C°, D°, for every tenth day:

$A^\circ = -20''{\cdot}47 \cos\omega \cos \odot$ $B^\circ = -20''{\cdot}47 \sin \odot$

$C^\circ = t - ''{\cdot}025 \sin 2L$ $D^\circ = - ''{\cdot}551 \cos 2L$

Date.		t in Days.	A°.	B°.	C°.	D°.	3·072 C°.
Jan.	1	0	− 3·25	+ 20·16	·008	+ ·52	·026
	11	10	6·46	19·22	·043	·42	·133
	21	20	9·48	17·67	·076	·28	·234
	31	30	12·19	15·56	·107	+ ·10	·328
Feb.	10	40	14·52	12·98	·134	− ·08	·412
	20	50	16·37	10·01	·159	·26	·488
Mar.	2	60	17·73	6·74	·181	·41	·556
	12	70	18·54	+ 3·28	·201	·51	·617
	22	80	18·78	− 0·26	·220	·55	·676
Apr.	1	90	18·46	3·77	·239	·52	·733
	11	100	17·60	7·14	·259	·44	·795
	21	110	16·22	10·32	·280	·30	·860
May	1	120	14·39	13·14	·304	− ·13	·935
	11	130	12·15	15·60	·331	+ ·06	1·017
	21	140	9·60	17·61	·361	·24	1·108
	31	150	6·76	19·10	·393	·40	1·207
June	10	160	3·76	20·06	·428	·50	1·314
	20	170	− 0·66	20·45	·464	·55	1·423
	30	180	+ 2·46	20·29	·499	·53	1·534
July	10	190	5·52	19·57	·534	·45	1·641
	20	200	8·41	18·30	·568	·32	1·744
	30	210	11·08	16·52	·599	+ ·15	1·840
Aug.	9	220	13·45	14·29	·627	− ·03	1·926
	19	230	15·45	11·63	·652	·22	2·004
	29	240	17·01	8·66	·675	·37	2·074
Sept.	8	250	18·10	5·40	·696	·49	2·138
	18	260	18·69	− 1·98	·715	·55	2·197
	28	270	18·72	+ 1·49	·734	·54	2·255
Oct.	8	280	18·22	4·97	·753	·47	2·314
	18	290	17·16	8·31	·774	·34	2·379
	28	300	15·58	11·43	·798	− ·18	2·450
Nov.	7	310	13·53	14·21	·824	+ ·01	2·530
	17	320	11·04	16·57	·853	·20	2·620
	27	330	8·21	18·42	·884	·36	2·717
Dec.	7	340	5·09	19·69	·918	·48	2·821
	17	350	+ 1·82	20·37	·954	·54	2·931
	27	360	− 1·50	20·41	·990	·55	3·041
	37	370	− 4·79	+ 19·80	1·025	+ ·48	3·147

The figures are natural numbers, not logarithms, and it is suggested that $A^\circ a$, &c., be computed with Crelle's "Rechentafeln."

Values of x and y:

$$x = \dot{-}\ \cdot 342 \sin \Omega + \cdot 004 \sin 2\Omega$$
$$y = -9\cdot 21 \ \cos \Omega + \cdot 09 \ \cos 2\Omega$$

Argument ☊. (*Long. of Moon's Ascending Node.*)

☊.	x.	y.	☊.	x.	y.	☊.	x.	y.	☊.	x.	y.
0°	·000	−9·12	90°	−·342	−0·09	180°	·000	+9·30	270°	+·342	−0·09
	5·8	0·8		0·2	16·0		6·0	0·6		0·4	16·0
5	−·029	−9·08	95	−·341	+0·71	185	+·030	+9·27	275	+·340	−0·89
	5·8	2·0		0·6	16·0		6·0	2·2		0·8	15·8
10	−·058	−8·98	100	−·338	+1·51	190	+·060	+9·16	280	+·336	−1·68
	5·6	3·2		1·2	15·8		6·2	3·6		1·4	15·6
15	−·086	−8·82	105	−·332	+2·30	195	+·091	+8·98	285	+·329	−2·46
	5·6	4·6		1·6	15·6		5·8	5·2		2·0	15·2
20	−·114	−8·59	110	−·324	+3·08	200	+·120	+8·72	290	+·319	−3·22
	5·4	6·0		2·2	15·2		5·4	6·4		2·4	14·6
25	−·141	−8·29	115	−·313	+3·84	205	+·147	+8·40	295	+·307	−3·95
	5·4	7·2		2·6	14·2		5·4	7·6		2·8	14·0
30	−·168	−7·93	120	−·300	+4·56	210	+·174	+8·02	300	+·293	−4·65
	5·0	8·4		3·2	13·8		5·2	9·0		3·4	13·4
35	−·193	−7·51	125	−·284	+5·25	215	+·200	+7·57	305	+·296	−5·32
	4·6	9·4		3·6	13·0		4·8	10·0		3·6	12·4
40	−·216	−7·04	130	−·266	+5·90	220	+·224	+7·07	310	+·258	−5·94
	4·4	10·4		4·0	12·2		4·4	11·2		4·0	11·6
45	−·238	−6·52	135	−·246	+6·51	225	+·246	+6·51	315	+·238	−6·52
	4·0	11·6		4·4	11·2		4·0	12·2		4·4	10·4
50	−·258	−5·94	140	−·224	+7·07	230	+·266	+5·90	320	+·216	−7·04
	3·6	12·4		4·8	10·0		3·6	13·0		4·6	9·4
55	−·276	−5·32	145	−·200	+7·57	235	+·284	+5·25	325	+·193	−7·51
	3·4	13·4		5·2	9·0		3·2	13·8		5·0	8·4
60	−·293	−4·65	150	−·174	+8·02	240	+·300	+4·56	330	+·168	−7·93
	2·8	14·0		5·4	7·6		2·6	14·4		5·4	7·2
65	−·307	−3·95	155	−·147	+8·40	245	+·313	+3·84	335	+·141	−8·29
	2·4	14·6		5·4	6·4		2·2	15·2		5·4	6·0
70	−·319	−3·22	160	−·120	+8·72	250	+·324	+3·08	340	+·114	−8·59
	2·0	15·2		5·8	5·2		1·6	15·6		5·6	4·6
75	−·329	−2·46	165	−·091	+8·98	255	+·332	+2·30	345	+·086	−8·82
	1·4	15·6		6·2	3·6		1·2	15·8		5·6	3·2
80	−·336	−1·68	170	−·060	+9·16	260	+·338	+1·51	350	+·058	−8·98
	0·8	15·8		6·0	2·2		0·6	16·0		5·8	2·0
85	−·340	−0·89	175	−·030	+9·27	265	+·341	+0·71	355	+·029	−9·08
	0·4	16·0		6·0	0·6		0·2	16·0		5·8	0·8
90	−·342	−0·09	180	−·000	+9·30	270	+·342	+0·09	360	·000	−9·12

(10) When my tables are computed—and this will in future require only about two hours' work per annum—I do not even

have to interpolate for odd minutes, because the various quantities required to correct the observed position are not applied separately to each star. Instead, a small table is computed for each day which gives:

(*a*) The sum of all corrections for $-36°$, and for each half hour of R.A. (clock error + reduction + m + n tan $\hat{c}$ + annual precession, &c.).

(*b*) The variation for an increase or decrease of 5° N.P.D.

For this purpose the corrections K_a, N_a, K_b, N_b are taken direct from the tables, the only interpolation being for N considered as a function of t, and this is very simple.

(11) I venture to suggest that much time might be saved in future if standard tables were computed and published, and it might also be practicable to publish annual tables.

Observations of Jupiter's Sixth Satellite, from Photographs taken at the Royal Observatory, Greenwich 1906 August.

(*Communicated by the Astronomer Royal.*)

Photographs of *Jupiter's* sixth satellite were obtained on 1906 August 28 and August 31 with the 30-inch reflector, with exposures of 28 mins. and 45 mins. respectively. *Jupiter* and the satellite and six reference stars, whose places were derived from the Astronomische Gesellschaft Catalogue, were measured, and the following right ascensions and declinations, with the corresponding position-angles and distances, deduced :—

Date and G.M.T. 1906.	Satellite VI. App. R.A.	Satellite VI. App. Decl.	Jupiter. App. R.A.	Jupiter. App. Decl.	Deduced. Pos. Angle.	Deduced. Distance.
d h m s	h m s	° ′ ″	h m s	° ′ ″	°	″
Aug. 28 15 27 29	6 22 42·60	+22 37 48·1	6 23 40·85	+23 3 2·6	208·046	1715·2
31 15 28 32	6 54 58·69	+22 36 25·1	6 25 47·31	+22 1 58·7	203·708	1674·5

From the measures of *Jupiter* the apparent corrections to the tabular place are :—

	R.A.	Decl.
	s	″
Aug. 28	−·06	+2·3
31	−·11	+1·8

The deduced position-angles and distances of the satellite reckoned from the tabular place of *Jupiter* would be

	Pos. Angle.	Distance.
	°	″
Aug. 28	208·108	1713·6
31	203·781	1673·4

instead of the values given above from the direct measures of *Jupiter* and the satellite.

Further photographs are being taken at every favourable opportunity.

Royal Observatory, Greenwich:
1906 *September* 21.

Measures of Southern Binary Stars. By John Tebbutt.

The following are the results of measures of six of the most interesting binary stars of the southern hemisphere. The measures were made with the Grubb 8-inch equatorial either in sunlight or in twilight; those of position-angle with the Cooke & Sons, and those of distance with the Grubb filar micrometer. The following method was employed for each star. The star was measured on three groups of evenings, the same micrometer being employed for the first and third groups, and the other micrometer for the middle group. The means of these three sets of measures duly weighted were then taken, and the means for the first and third sets reduced to the epoch corresponding to the mean of the middle group. It may be stated that ten measures at least in each coordinate were taken of each star on each night of the groups.

Star.	Epoch.	Position-angle.	Distance	No. of Evenings for Position-angle	No. of Evenings for Distance.	Hour Angle.
p Eridani ...	1906·161	219°·8	8″·90	4	4	W.
γ Centauri ...	1905·471	352·9	1·52	8	6	E. & W.
β Muscæ ...	1905·726	345·0	1·33	6	3	W.
α Centauri ...	1905·476	212·1	21·16	7	12	W. & E.
β 416 ...	1905·618	279·3	2·38	4	4	E.
γ Coronæ Aust. ...	1905·650	123·5	1·69	6	4	E.

Observatory, Peninsula, Windsor, N.S. Wales:
1906 *July* 17.

Ephemeris of Flora near the time of Opposition in 1907.
By A. M. W. Downing, D.Sc., F.R.S.

This ephemeris is computed from Brünnow's "Tafeln der Flora," in combination with the corrected continuation of certain of the tables published in *Monthly Notices*, vol. lxiv. No. 6.

Berlin Midnight.	Apparent R.A.	Apparent Dec.	Log. Distance from Earth.
1907.	h m s	° ′ ″	
Jan. 4	7 47 3·26	+20 56 47·6	0·03832
5	45 56·64	21 3 36·8	·03814
6	44 49·22	10 25·9	·03807
7	43 41·11	17 14·6	·03811
8	42 32·42	24 2·4	·03825
9	41 23·26	30 48·9	·03850
10	40 13·75	37 33·8	·03885
11	39 4·02	44 16·5	·03931
12	37 54·17	50 56·7	·03987
13	36 44·33	21 57 34·0	·04054
14	35 34·63	22 4 7·9	·04131
15	34 25·19	10 37·9	·04218
16	33 16·14	17 3·6	·04315
17	32 7·58	23 24·5	·04423
18	30 59·63	29 40·2	·04541
19	29 52·41	35 50·4	·04669
20	28 46·02	41 54·9	·04807
21	27 40·57	47 53·4	·04954
22	26 36·15	53 45·6	·05110
23	25 32·86	22 59 31·3	·05276
24	24 30·81	23 5 10·4	·05451
Jan. 25	7 23 30·09	+23 10 42·6	0·05635

Magnitude at Opposition, January 13 = 8·6.

LIST OF ADDITIONS

TO THE LIBRARY

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JUNE 1905 TO JUNE 1906.

An asterisk (*) indicates that the work is an excerpt.

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